Kansas Water Resources Research Institute Annual Technical Report FY 2015

Introduction

The Kansas Water Resources Institute (KWRI) is part of a national network of water resources research institutes in every state and territory of the U.S. established by law in the Water Resources Research Act of 1964. The network is funded by a combination of federal funds through the U.S. Department of the Interior/Geological Survey (USGS) and non-federal funds from state and other sources.

KWRI is administered by the Kansas Center for Agricultural Resources and the Environment (KCARE) at Kansas State University. An Administrative Council comprised of representatives from participating higher education or research institutions, state agencies, and federal agencies assists in policy making.

The mission of KWRI is to: 1) develop and support research on high priority water resource problems and objectives, as identified through the state water planning process; 2) facilitate effective communications among water resource professionals; and 3) foster the dissemination and application of research results.

We work towards this mission by: 1) providing and facilitating a communications network among professionals working on water resources research and education, through electronic means, newsletters, and conferences; and 2) supporting research and dissemination of results on high priority topics, as identified by the Kansas State Water Plan, through a competitive grants program.

Research Program Introduction

Our mission is partially accomplished through our competitive research program. We encourage the following through the research that we support: interdisciplinary approaches; interagency collaboration; scientific innovation; support of students and new young scientists; cost-effectiveness; relevance to present and future water resource issues/problems as identified by the State Water Plan; and dissemination and interpretation of results to appropriate audiences.

In implementing our research program, KWRI desires to: 1) be proactive rather that reactive in addressing water resource problems of the state; 2) involve the many water resources stakeholders in identifying and prioritizing the water resource research needs of the state; 3) foster collaboration among state agencies, federal agencies, and institutions of higher education in the state on water resource issues; 4) leverage additional financial support from state, private, and other federal sources; and 5) be recognized in Kansas as a major institution to go to for water resources research.

Moving Towards a Real-Time Drought Assessment and Forecasting System for Kansas

Basic Information

Title:	Moving Towards a Real-Time Drought Assessment and Forecasting System for Kansas
Project Number:	2014KS170B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-001
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, None, None
Descriptors:	None
Principal Investigators:	Xiaomao Lin, Robert Aiken, Gerard J. Kluitenberg, Daniel OBrien

Publications

1. Zhang, T., X. Lin, D. H. Rogers, and F. R. Lamm. 2015: Adaptation of irrigation infrastructure on irrigation demands under future drought in the USA. Earth Interactions doi: http://dx.doi.org/10.1175/EI-D-14-0035.1
2. Zhang, T., and X. Lin, 2016: Assessing future drought impacts on yields based on historical irrigation reaction to drought for four major crops in Kansas. Science of the Total Environment, 550, 851-860.
3. Lin, X., R. A. Pielke Sr, R. Mahmood, C. A. Fiebrich, and R. Aiken, 2016: Observational vidence of temperature trends at two levels in the surface layer. Atmos. Chem. Phys., 16, 827-841.

KIWR Project Progress Report in 2016 (from March 2015 to Feb 2016)

Moving Towards A Real-Time Drought Assessment and Forecasting System for Kansas

Xiaomao Lin, Gerard Kluitenberg, Robert Aiken, and Daniel O'Brien

This study has three objectives which were:

1) To construct an integrated drought-related dataset, suitable for Kansas drought assessment and forecasting;

2) To develop computational tools for computing three drought indices: *Palmer Drought Severity Index* (PDSI), *Standardized Precipitation Index* (SPI), and *Standardized Precipitation Evapotranspiration Index* (SPEI); and

3) To analyze historic drought episodes, establishing Kansas's benchmark metrics for detecting the onset, duration, severity and frequency of drought.

As we previously reported last year we completed the Objective 1 and Objective in year 1. During the second year we have successfully completed Objective 3 along with an evaluation of drought forecasting skills in Kansas. We have completed statistical downscaling modeling for Kanas by using NCEP CFSv2.0 reanalysis forecasts products. Kansas drought information now is at our website http://climate.k-state.edu/drought/.

In terms of graduate student's training in this project, Zach Zambreski (MS student) is a recipient of Timothy R. Donoghue Graduate Scholarship. Zach is planning to complete his MS degree program in Aug, 2016 for his thesis defense. We also planned to send him in the 2016 ASA annual conference and 2017 AMS annual conference

During the past year, we have following presentations and articles were published and one manuscript is in revision. These publications are

Presentations from our project

1. Lin, X., G. Kluitenberg, R. Aiken, M. Knapp, 2014: Kansas droughts: history, current, and future. Governor's Conference on the Future of Water in Kansas. Nov. 2014. Manhattan, KS.
2. Lin, X. 2015: Kansas drought characteristics over last century. The Drought warning assessment workshop. March, 2015. Lincoln, NE.
3. Lin, X., G. Kluitenberg, R. Aiken, M. Knapp, 2014: Kansas droughts: history, current, and future. The Kansas Hydrology Seminar, University of Kansas. Dec. 2014. Lawrence, KS.
4. Lin, X. 2016: Kansas climate, climate change, and crop responses. The KSU climate group. May, 2016. Manhattan, KS
5. Zambreski, Z., X. Lin, and G. Kluitenberg, 2015: Wheat yield responses to multiple drought indices from 1970 to 2007 in Kansas. Governor's Conference on the Future of Water in Kansas, November 2015, Manhattan, KS.

6. Zambreski, Z., X. Lin, and G. Kluitenberg, 2015: Characterizing the spatiotemporal characteristics of drought occurrence in Kansas using multiple indices. 2015 Annual Meeting of the American Society of Agronomy, Nov. 15 -17, 2015; Minneapolis, MN.
7. Zambreski, Z, and X. Lin, 2016: Crop-seasonal prediction of wheat yields using drought and extreme temperature indices in the U.S. wheat belt. April, 2016. 2016 Water for Food Global Conference. Lincoln, NE.
8. Zambreski, Z, and X. Lin, 2016: Crop-seasonal prediction of wheat yields using drought and extreme temperature indices in the U.S. wheat belt. April, 2016. 2016 Water for Food Global Conference. Lincoln, NE.

Manuscript in revision

Zambreski Z. X. Lin, G. Kluitenberg, R. Aiken 2016: The spatiotemporal characteristics of drought occurrences in Kansas using multiple indices. *International journal of climatology*.

Extending the Useable Life of Ogallala Aquifer through Limited Irrigation using Integrated Sensor-Based Technologies

Basic Information

Title:	Extending the Useable Life of Ogallala Aquifer through Limited Irrigation using Integrated Sensor-Based Technologies
Project Number:	2014KS171B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-001
Research Category:	Ground-water Flow and Transport
Focus Category:	Irrigation, None, None
Descriptors:	None
Principal Investigators:	Isaya Kisekka, Jonathan P Aguilar, Randall Currie, Danny H. Rogers

Publication

1. Kisekka, I., J. Aguilar, F.R. Lamm, and D. H. Rogers. 2014. Using Soil Water and Canopy Temperature to Improve Irrigation Scheduling for Corn. Technical Proceedings of the 2014 Irrigation Association Technical Conference, Phoenix, Arizona, November 19-20, Available at: from the Irrigation Association, Falls Church, Virginia.

Title: Extending the usable Life of Ogallala Aquifer through Limited Irrigation using Integrated Sensor-Based Technologies

Research Category: Ground-water Flow and Transport

Focus Category: Irrigation

Primary PI: Isaya Kisekka, Kansas State University (KSU) Southwest Research and Extension Center (SWREC), E. Mary St., Garden City, KS, ikisekka@ksu.edu, (620)-275-9164.

Other PIs: Jonathan Aguilar, KSU SWREC, E. Mary St., Garden City, KS, jaguilar@k-state.edu, (620)-275-9164, Danny Rogers, KSU, Biological and Agricultural Engineering Department, 151 Seaton Hall Manhattan, KS, drogers@ksu.edu, (785) 532-2933 and Randall Currie (SWREC, Garden City, KS), KSU SWREC, E. Mary St., Garden City, KS, rscurrie@ksu.edu, (620)-275-9164.

Executive Summary

With declining well capacities in the Central High Plains resulting from withdrawals exceeding recharge in the Ogallala aquifer, producers will need to adopt advanced irrigation scheduling to maintain productivity with limited water. A study was conducted to assess the effect of 3 irrigation scheduling approaches on corn yield, and water productivity, and water use. Irrigation scheduling approaches based on soil and plant water status monitoring coupled with ET-based water balance were evaluated. The study involved five irrigation scheduling treatments applying 80% of full irrigation and a control (full irrigation applying 100% ET) treatment and two corn hybrids arranged in a split-plot Randomized Complete Block Design (RCBD) design.

Results from 2015 and 2016 growing season indicate the effect of irrigation scheduling method on grain yield was not significant in 2014 (p-value=0.38). However, the effect of irrigation scheduling method on grain yield was significant in 2015 (p-value=0.03). The contradictory results are due to having differential initial soil water at planting among treatments in 2014. Low soil water at planting masked the benefits of irrigation scheduling in 2014. In 2015, all the treatments started with approximately the same profile soil water and under this scenario the effect of irrigation scheduling method was significant. Irrigation scheduling based on canopy temperature was not significantly different from the scientific standard method of irrigation scheduling based on soil water monitoring using a neutron probe. In fact, the irrigation scheduling method that was based on both soil water sensor and canopy temperature triggers produced similar yields to the standard irrigation scheduling method. These results indicate that either canopy temperature based irrigation scheduling or irrigation scheduling using calibrated TDR based soil water sensors can maintain yields while eliminating unnecessary irrigations. To further enhance confidence among irrigators, combining soil water and plant water status sensors with ET-based water balance should be promoted. Reducing irrigation by 20% did not substantially reduce corn yields.

In both 2014 and 2015, the effect of irrigation scheduling method on water productivity was not significant (p-value>0.05). The effect of irrigation scheduling method on irrigation water use efficiency (IWUE) was highly significant in 2014 and 2015 with p-value<0.0001 in both years. Treatments based on canopy temperature or a combination of canopy temperature and soil water sensor triggers applied the least irrigation amount; they were able to optimize water use by using more of the rainfall and available soil water at planting to meet crop water use. This implies that there were opportunities to eliminate

unnecessary irrigations particularly in wet years which could improve water productivity and IWUE. Integrating soil and plant water status monitoring with the scientifically robust ET-based scheduling could encourage more producers to adopt irrigation scheduling particularly if delivered with visual illustrations of root water uptake or images of crop water stress.

Experimental Site Characteristics

The study was conducted at the Kansas State University Southwest Research and Extension Center Finnup farm (38º01’20.87’’N, 100º49”26.95W, elevation of 2,910 feet above mean sea level) near Garden City, Kansas. A four span (140 feet span width) lateral move sprinkler irrigation system (model 8000, Valmont Corp., Valley, NE) was used to apply irrigation water. The experimental design was a split-plot randomized complete block design with four replications. Each span was a replication with six treatments. Irrigation scheduling was the main factor while subplots were corn hybrids (drought tolerant and conventional) as shown in Fig.1.

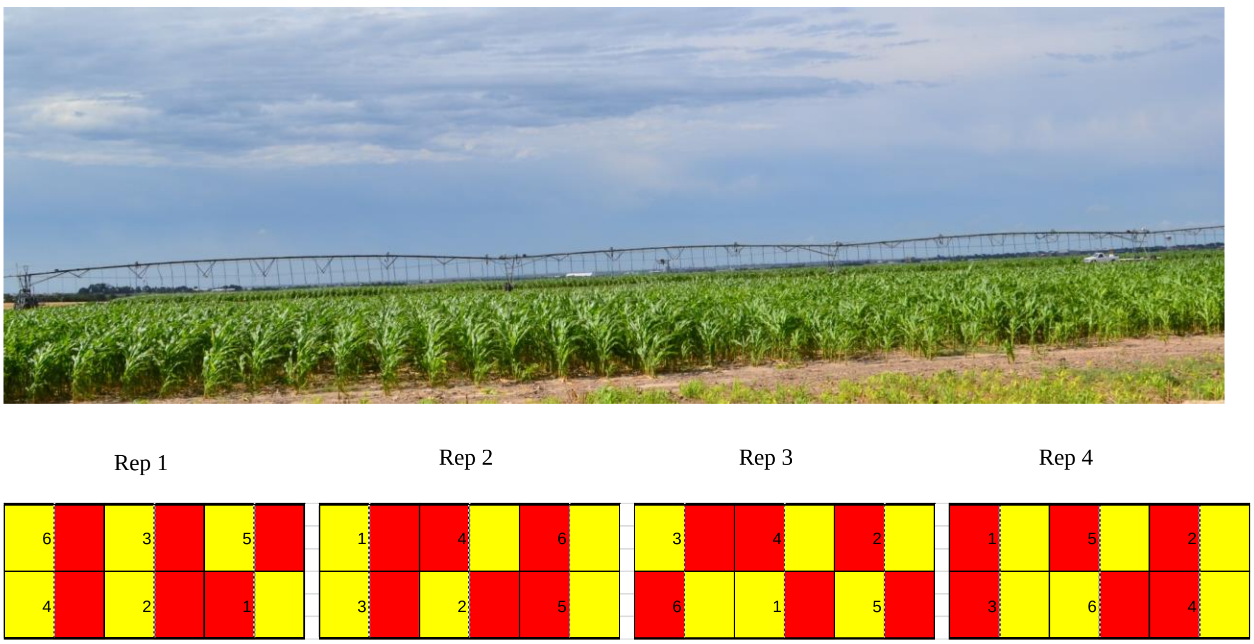

Figure 1. Linear move sprinkler system and split-plot randomized complete block design experimental layout where numbers within the plots represent irrigation treatment and yellow and red colors present conventional and drought tolerant corn hybrids respectively, at Kansas State University SWREC nearGarden City, Kansas.

Irrigation Water Management Treatments

The six irrigation scheduling treatments that were evaluated included:

1. Irrigate when available soil water (ASW) in the root zone reaches 60% ASW based on weekly soil water measurements with a neutron probe.
2. Irrigate when the canopy’s time-temperature-threshold (TTT) exceeds 28ºC for more than 240 minutes.
3. Irrigate when ASW in the root zone falls reaches 60% ASW based on soil water sensor measurements.

4. Irrigate when the crop water stress index (CWSI) threshold exceeds 0.3 or ASW falls below 60% based on soil water sensor measurements
5. Irrigate only if data from both soil water and CWSI indicate that thresholds have been exceeded
6. Control treatment replenishing 100% ET based on ET water balance (Full irrigation)

An ET-based water budget was kept for each treatment. Each irrigation event applied 1 inch and replenished only 80% of the accumulated ET with the exception of treatment 6.

Soil Water Status Sensing

Soil water sensors were installed to serve as checks on the adequacy of the ET-based irrigation schedules and also to indicate the need for irrigation. Soil water sensors (CS655; Campbell Scientific Inc., Logan UT, USA) were installed in treatments 3, 4, and 5 in the drought tolerant hybrid. Soil water sensors were only temporally installed in rep 1 during the first year of the study (2014) due to delays in procuring the sensors and wet conditions in the early part of the season that made field operations difficult. Each set of soil water sensors comprised of three sensors placed at depths of 1, 2, and 3 feet as shown in Fig. 2. However, soil water sensors were permanently installed in all the replications during the second of the study (2015).

Figure 2. Different stages of installing CS655 soil water sensors in corn plots during the 2015 summer growing season at Kansas State University SWREC near Garden City.

Plant Water Status Sensing

Infrared radiometers (SI-111: 22º half angle field of view, spectral range 8 to 14 µm, Apogee Instruments Inc., Logan UT, USA) were installed to monitor canopy temperature in drought tolerant corn hybrids. A total of 12 infrared radiometers were required in treatments 2, 4, and 5 by four replications. The sensors were positioned approximately 3 feet above the crop canopy at a 45^{o} from the horizontal view angle as shown in Fig. 3.

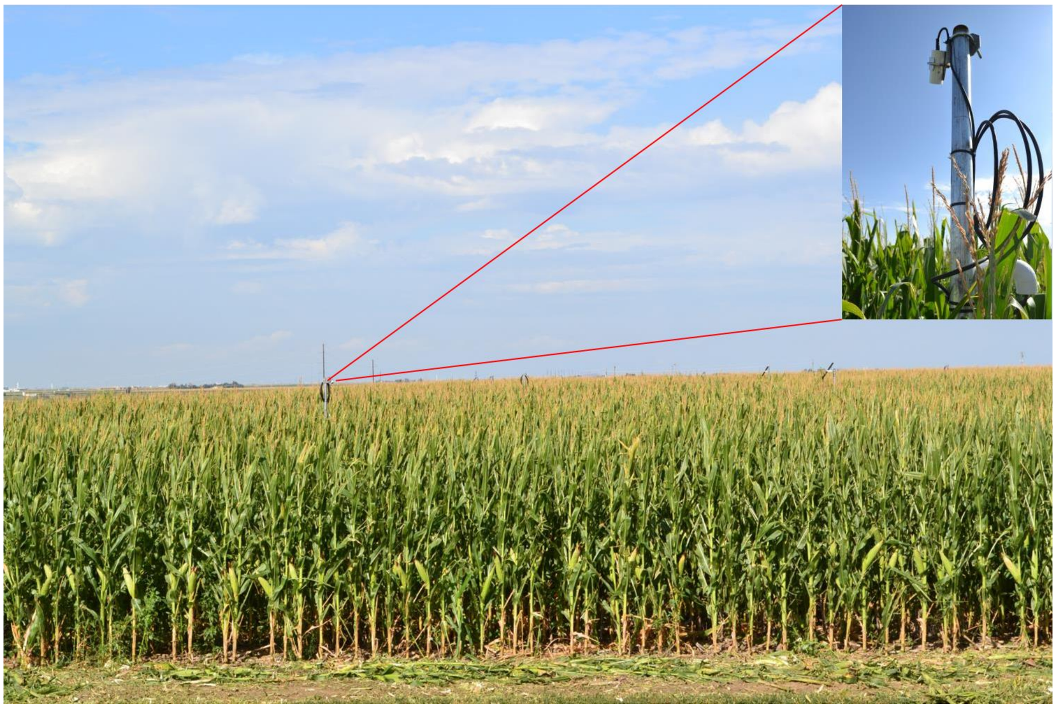

Figure 3. Monitoring corn canopy temperature using thermal infrared radiometers during the 2014 summer growing season at the Kansas State University SWREC near Garden City, Kansas.

Statistical Analysis

Statistical analysis was performed using the PROC GLIMMIX model in SAS Studio (Zhu, 2014).

Results and Discussions

Corn Grain Yield

Average yields and seasonal crop evapotranspiration for the different irrigation scheduling methods and two corn hybrids are summarized in Tables 1 and 2. The effect of irrigation scheduling method (i.e., based on soil or plant water status monitoring or ET) on grain yield was not significant in 2014 (p-value=0.38). However, the effect of irrigation scheduling method on grain yield was significant in 2015 (p-value=0.03). The effect of corn hybrid (with or without drought tolerant trait) was significant in 2014 (p-value=0.003), but not significant in 2015 (p-value=0.5). The conventional hybrid produced more grain yield compared to the drought tolerant hybrid. The effect of the interaction between irrigation scheduling method and corn hybrid on grain yield was not significant in both years with p-value=0.5 and p-value=0.8 in 2014 and 2015 respectively. The contradictory results from the two years of this study are probably due to the effect of initial profile soil water content at the time of planting. In 2014, a previous study in the same location resulted in having differential soil water contents between treatments plots. Treatments 1 to 3 were located in plots that had higher starting profile soil water compared to treatments 4 to 6 as shown in Fig 4. It can be seen in Table 1 that treatments 1 to 3 produced higher yield than treatments 4 to 6 irrespective of the irrigation scheduling treatment. In 2014, treatment 6 that received 100% produced less yield than some of the treatments that received 80% ET. Having sufficient soil water at planting helps to protect the crop from intermittent water stress by providing a buffer to the crop between irrigation or rainfall events. Avoiding water stress earlier in the season could help set higher yield potential.

In 2015, all the treatments started approximately with the same profile soil water as shown in Fig. 4, and under this scenario the effect of irrigation scheduling method was significant. Treatment 1 based on soil water monitoring using a neutron probe was used as standard scientific irrigation scheduling method for comparison with other treatments. Irrigation scheduling based on canopy temperature (using the time temperature threshold (T2) or crop water stress index (T4 & T5)) was not significantly different from Treatment 1. In fact, the irrigation scheduling method that was based on both soil water and temperature triggers produced similar yields to T1. Treatment 3 based on soil water monitoring using the CS655 soil water sensors produced the highest yield of all irrigation scheduling treatments although the yields were not significantly different from T1 and T5. The control treatments (T6) receiving 100% ET produced yields that were not significantly different from irrigation scheduling treatments receiving only 80% ET. These results indicate that either canopy temperature based irrigation scheduling or irrigation scheduling using TDR based soil water sensors can produce yields that are not significantly different from those based on standard scientific irrigation scheduling using neutron probe. To further enhance confidence among irrigators, combining soil water and plant water status sensors with ET-based water balance should be promoted. The results also show that reducing full irrigation by 20% might not significantly impact corn yields if attention is taken to ensure sufficient soil water at planting at least (50% plant available water) in the top 4 feet of the soil profile at planting. Also, from Tables 1 and 2 it can be seen that there were no substantial differences in crop water use between the drought tolerant and conventional corn hybrids.

Table 1. Yield response to irrigation scheduling method and corn hybrid during the 2014 growing season at Kansas State University SWREC near Garden City, Kansas.

Treatments[1]	Yield (bu/ac)		Yield (bu/ac)		Seasonal ETc (in)	
	Conventional	Std.[2]	Drought Tolerant	Std.	Conventional	Drought Tolerant
T1	206 a[4]	32	181 b	18	20.1 (1.1)[3]	20.4 (0.4)
T2	209 a	13	189 b	13	20.6 (0.5)	20.6 (1.0)
T3	219 a	23	179 b	23	20.3 (0.6)	20.2 (1.4)
T4	182 a	26	186 b	17	19.4 (1.0)	21.9 (0.8)
T5	192 a	12	173 b	22	19.4 (0.5)	20.6 (0.6)
T6	189 a	8	173 b	32	21.5 (1.0)	21.3 (1.3)
		*[5]				

[1]Irrigation scheduling treatments: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28º C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.
[2]Standard deviation
[3]Numbers in parentheses are standard deviations
[4]Treatments with different letters are significantly different at 5% based on Tukey's test

[5]Indicates significant differences between conventional and drought tolerant corn at 5% level.

Table 2. Yield response to irrigation scheduling method and corn hybrid during the 2015 growing season at Kansas State University SWREC near Garden City, Kansas.

Treatments	Yield (bu/ac)		Yield (bu/ac)		Seasonal ETc (in)	
	Conventional	Std.1	Drought Tolerant	Std.	Conventional	Drought Tolerant
T1	199 ab[4]	40	198 ab	46	20.9 (0.7)	21.4 (0.8)
T2	183 b	46	180 ab	31	19.2 (0.4)	19.1 (1.3)
T3	225 a	14	199 ab	26	20.7 (1.2)	20.9 (2.1)
T4	180 b	45	196 ab	66	19.5 (1.8)	19.3 (0.6)
T5	186 ab	7	173 b	48	19.2 (0.5)	18.5 (1.4)
T6	227 a	26	216 a	27	22.0 (1.4)	21.9 (0.9)
		NS[5]				

[1]Irrigation scheduling treatments: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28° C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.
[2]Standard deviation
[3]Numbers in parentheses are standard deviations
[4]Treatments with different letters are significantly different at 5% based on Tukey's test
[5]Indicates no significant differences between conventional and drought tolerant corn at 5% level

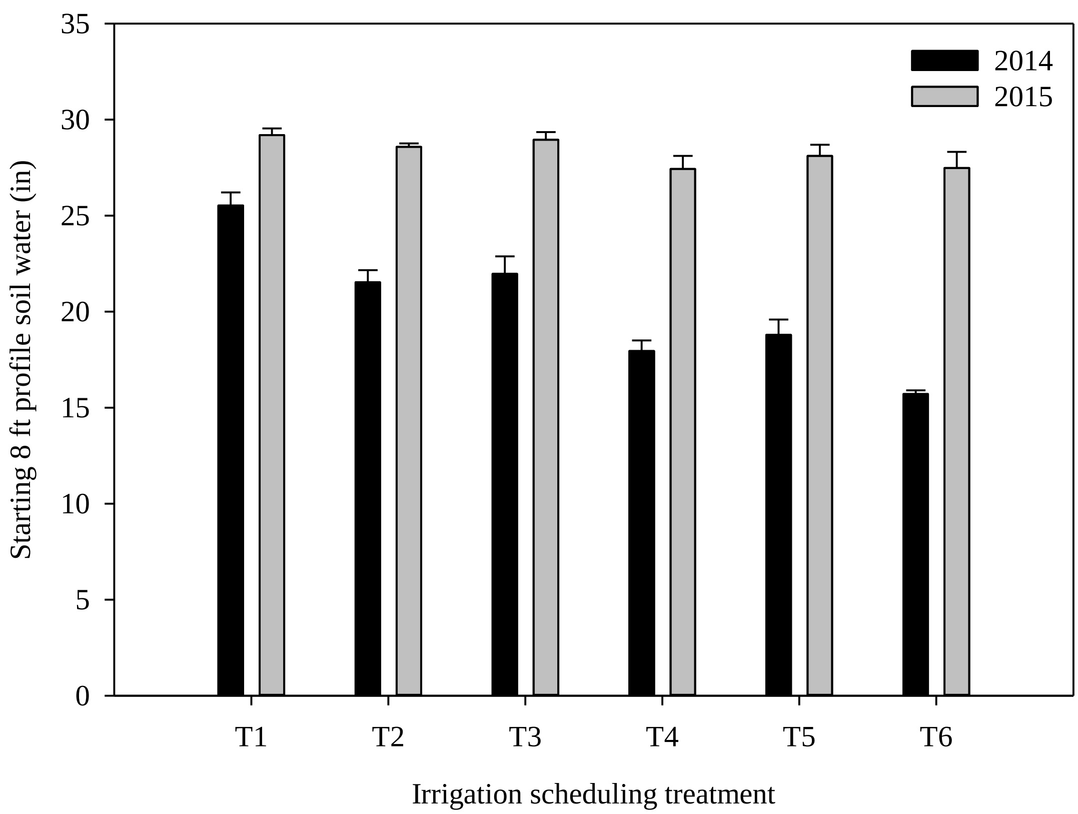

Fig. 4. Initial soil water in an 8 ft soil profile for the different irrigation scheduling treatments at the Kansas State University SWREC near Garden City, Kansas. Where irrigation treatments are defined as follows: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28^{o} C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.

Water Productivity and Irrigation Water Use Efficiency

Crop water productivity (CWP) and irrigation water use efficiency (IWUE) are summarized in Tables 3 and 4. In both 2014 and 2015, the effect of irrigation scheduling method on water productivity was not significant with p-value=0.14 and p-value=0.42 in 2014 and 2015 respectively. The effect of corn hybrid on water productivity was significant in 2014 (p-value=0.0.01) but not in 2015 (p-value=0.55), probably due to the fact that differential initial soil water among treatments affected yields. The conventional corn hybrid produced higher crop water productivity compared to the drought tolerant hybrid in 2014, with treatments that started with higher profile soil water (T1, T2 and T3) producing 10% higher water productivity compared to treatments that started with lower soil water. In 2015, there were no substantial differences in water productivity between treatments. The 2015 results are more realistic since all treatments started with about the same profile soil water at planting. The lack of significant differences in water productivity is due to the fact that there were no substantial differences in grain yield and seasonal crop water use among irrigation scheduling treatments 1 through 5. This indicates that any of the soil or plant water status based irrigation methods coupled with ET could help farmers improve their water productivity, particularly under deficit irrigation.

Irrigation water use efficiency (IWUE) results are summarized in Tables 3 and 4. The effect of irrigation scheduling method on irrigation water use efficiency (IWUE) was highly significant in 2014 and 2015 with p-value<0.0001 in both years. The effect of corn hybrid or drought tolerant trait on IWUE was significant in 2014 and not significant in 2015. Results in 2014 were confounded by variation in starting profile soil water between treatments and therefore results from 2015 are more representative since all treatments started with approximately the same soil water. Treatment 5 based on both soil water and canopy temperature produced the highest IWUE followed by Treatment 3 based on canopy temperature and the time temperature threshold, no significant differences in IWUE between treatments 1,3, 4 and 6. These results confirm what other studies (Idso et al. 1981; Jackson 1982; O'Shaughnessy and Evett, 2010) have shown that canopy temperature is an effective method of scheduling irrigation. Irrigation scheduling triggered by calibrated CS655 soil water sensors also produced IWUE that was not significantly different from T1 whose irrigation scheduling was based on soil water monitoring using a neutron probe. There was no significant difference IWUE between irrigation treatments receiving 80% of ET and Treatment 6 that received 100% ET, indicating their opportunities to reduce total irrigation applications without significant negative effect on corn grain yield. Table 5 shows the total irrigation water applied by treatment; it can be seen that Treatments 2 and 5 were able to optimize water use by using more of the rainfall and available soil water at planting to meet crop water use. Both 2014 and 2015 were wetter than normal with growing season (May to September) precipitation of 17.05 and 18.21 inches respectively, normal annual rainfall is about 18 inches. Lamm and Rogers (2015) showed that even under marginal well capacities there were opportunities to eliminate unnecessary irrigations particularly in wet years which could improve water productivity and IWUE.

Table 3. Crop Water Productivity and Irrigation Water Use Efficiency for 5 deficit irrigation scheduling methods and a control (full irrigation) during the 2014 growing season at Kansas State University SWREC near Garden City, Kansas.

Treatments[1]	CWP (bu/ac-in)		IWUE (bu/ac-in)	
	Conventional	Drought Tolerant	Conventional	Drought Tolerant
T1	10.3 (1.9) a[4]	8.9 (1.1) b	29 (5.2)[2] a	26 (3.0) a
T2	10.7 (0.8) a	9.6 (0.7) b	26 (1.6) ab	24 (1.9) ab
T3	10.8 (1.5) a	8.9 (1.2) b	24 (3.0) b	20 (3.0) c
T4	9.4 (1.2) a	8.9 (1.3) b	18 (3.1) c	19 (1.9) c
T5	9.9 (0.6) a	8.8 (1.0) b	24 (1.7) b	22 (3.1) bc
T6 (Full)	9.2 (0.3) a	8.2 (2.3) b	16 (0.8) c	14 (3.1) d
		NS[5]		NS

[1]Irrigation scheduling treatments: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28º C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.

[3]Numbers in parentheses are standard deviations

[4]Treatments with different letters are significantly different at 5% based on Tukey's test

[5]Indicates no significant differences between conventional and drought tolerant corn at 5% level

Table 4. Crop Water Productivity and Irrigation Water Use Efficiency for 5 deficit irrigation scheduling methods and a control (full irrigation) during the 2014 growing season at Kansas State University SWREC near Garden City, Kansas.

Treatments[1]	CWP (bu/ac-in)		IWUE (bu/ac-in)	
	Conventional	Drought Tolerant	Conventional	Drought Tolerant
T1	9.6 (2.1) a	9.3 (1.1) a	40 (8.1)2 c	40 (9.2) c
T2	9.5 (2.4) a	9.4 (1.6) a	61 (15.3) b	60 (10.4) b
T3	10.9 (1.3) a	9.6 (1.4) a	45 (2.9) c	40 (5.1) c
T4	9.2 (2.2) a	10.2 (3.3) a	45 (11.1) c	49 (16.5) bc
T5	9.7 (0.6) a	9.4 (2.5) a	90 (3.7) a	86 (23.8) a
T6 (Full)	10.3 (0.7) a	9.9 (1.0) a	45 (5.2) c	43 (5.4) c
		NS[5]		NS[5]

[1]Irrigation scheduling treatments: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28º C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.

[3]Numbers in parentheses are standard deviations.

[4]Treatments with different letters are significantly different at 5% based on Tukey's test

[5]Indicates significant differences between conventional and drought tolerant corn at 5% level

Table 5. Irrigation applied to five deficit irrigation scheduling treatments (80% of full irrigation) and control (100% ET full irrigation) during the 2014 and 2015 growing seasons at Kansas State University SWREC near Garden City, Kansas.

Treatment[1]	In-season Irrigation (in)	Total Irrigation (in)	In-season Irrigation (in)	Total Irrigation (in)
	2014		2015	
T1	7	9	5	6
T2	8	10	3	4
T3	9	11	5	6
T4	10	12	5	6
T5	8	10	2	3
T6 (Full)	12	14	5	6

[1]Irrigation scheduling treatments: T1: Neutron probe based trigger of available soil water (ASW) < 60%, T2: Time Temperature Threshold (TTT)> 28^o C for 240 min.+, T3: CS655 TDR sensor based on trigger of ASW < 60%, T4: Crop Water Stress Index (CWSI)>0.3 or S. ASW<60% based on CS655 soil water sensors irrigate if either trigger is met, T5: CWSI>0.3 OR S. ASW<60% to irrigate both triggers must be met, and T6: Full irrigation 100% ET. Treatments 1 to 5 only received 80% of ET if trigger was met.

Soil Water

Soil water measurements from the CS655 soil water sensors were calibrated using field-calibrated neutron probe measurements. Prior to calibration, the sensor was overestimating soil water under wet conditions. However, after calibration using a simple linear regression (Y=0.1991X+0.2081, R^2=0.89), the sensors were able to accurately measure soil water. The soil water sensors were able to track wetting (from irrigation or rainfall) and drying cycles as shown in Figure 5 and diurnal fluctuations in soil water content indicating root water uptake during the day and near zero transpiration during the night as shown in Figure 6. These figures indicate that in addition to bulk soil electroconductivity and soil temperature data these types of multiparameter sensors provide, they could also be used to determine rooting depth; which could be useful in characterizing soil water extraction patterns of different hybrids. This data on root zone water use may increase the confidence of users of ET-based scheduling. Soil water monitoring using neutron probe to a depth of 8 ft in increments of 1 foot was used to confirm the adequacy of irrigation scheduling and to calculate seasonal crop water use using the soil water balance approach.

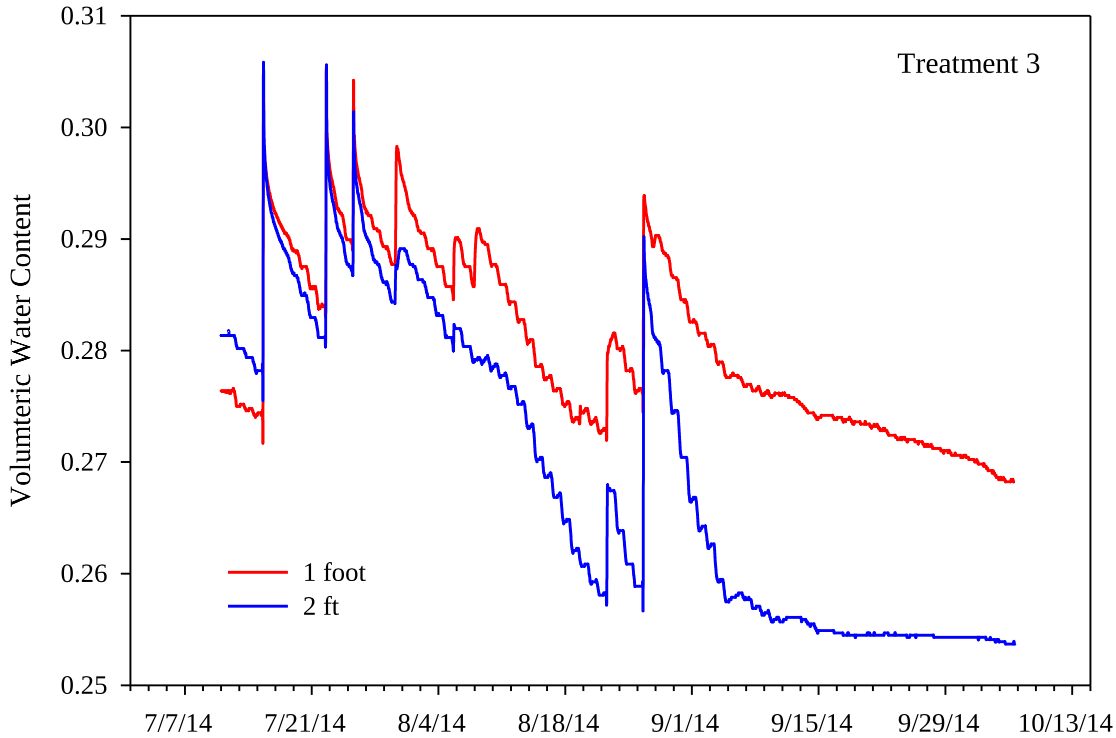

Figure 5. Soil water measurements at two different depths over time made by the CS655 soil water during the 2014 corn growing season at Kansas State University SWREC near Garden City, Kansas.
Garden City Kansas.

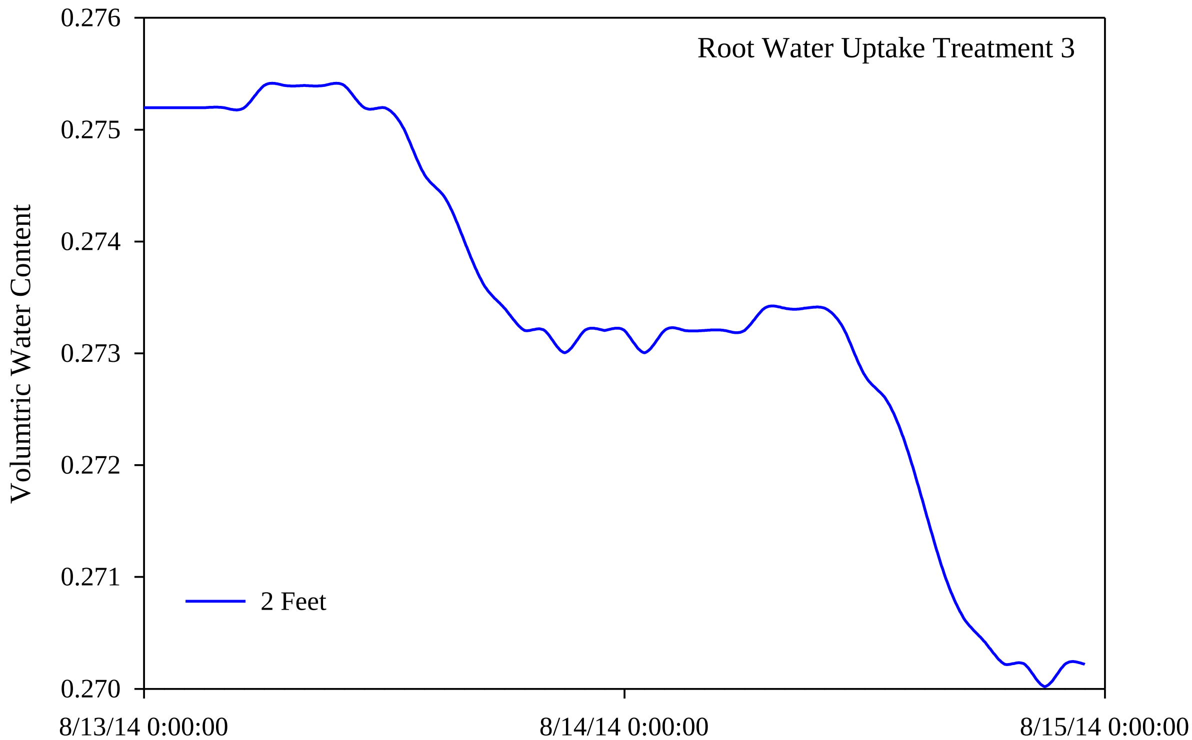

Figure 6 diurnal fluctuation in soil water. Illustration of root water uptake during the day and close to zero up take during the night.

Conclusion

Using irrigation scheduling based on soil or plant water status monitoring coupled ET-based water balance could help producers with constrained water supplies to improve water and crop productivity. Irrigation scheduling triggered by soil waters, and canopy temperature coupled with ET-based water balance were evaluated in corn (drought tolerant and conventional hybrid) under deficit irrigation (80% ET). The effect of irrigation scheduling method on grain yield was not significant in 2014. However, the effect of irrigation scheduling method on grain yield was significant in 2015. The contradictory results are due to having differential initial soil water at planting among treatments in 2014. Low soil water at planting could mask the benefits of irrigation scheduling. In 2015, all the treatments started approximately with the same profile soil water and under this scenario the effect of irrigation scheduling method was significant. Irrigation scheduling based on canopy temperature (using the time temperature threshold (T2) or crop water stress index (T4 and T5) was not significantly different from the scientific standard method of irrigation scheduling based on soil water monitoring using a neutron probe. In fact, the irrigation scheduling method that was based on both soil water sensor and canopy temperature triggers produced similar yields to the standard irrigation scheduling method. These results indicate that either canopy temperature based irrigation scheduling or irrigation scheduling using TDR based soil water sensors can produce yields that are not significantly different from those based on irrigation scheduling using neutron probe. To further enhance confidence among irrigators, combining soil water and plant water status sensors with ET-based water balance should be promoted. Reducing irrigation by 20% did not substantially reduce corn yields. In both 2014 and 2015, the effect of irrigation scheduling method on water productivity was not significant. The effect of irrigation scheduling method on irrigation water use efficiency (IWUE) was highly significant in 2014 and 2015 with p-value<0.0001 in both years. There was no significant difference IWUE between irrigation treatments receiving 80% of ET and control that received 100% ET, indicating their opportunities to reduce total irrigation applications without significant negative effect on corn grain yield. For producers with constrained, water supplies adopting irrigation scheduling based on calibrated TDR soil water sensors, canopy temperature sensors coupled with ET-based water balance could help maintain yields while eliminating unnecessary irrigation applications.

Acknowledgements

The authors would like to thank Kansas Water Resources Institute (KWRI) for providing funding. We would also like to thank Kansas State University SWREC for providing matching funds for this project. The authors would also like to thank Mr. Dennis Tomsicek who put in several hours to learn this new technology and make it work.

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Publications from this Grant:

Kisekka, I., J. Aguilar, F.R. Lamm, and D. H. Rogers. 2014. Using Soil Water and Canopy Temperature to Improve Irrigation Scheduling for Corn. Technical Proceedings of the 2014 Irrigation Association Technical Conference, Phoenix, Arizona, November 19-20, Available at: from the Irrigation Association, Falls Church, Virginia.

Kisekka, I., J. Aguilar, and D. H. Rogers. 2016. Integrating Sensor-based with ET-based Water Balance to improve Robustness of Irrigation Scheduling. Under preparation for submission to Journal of Applied Engineering in Agriculture.

Information Transfer Program

Research findings presented at the IA Irrigation Show and Education Conference November 17-21, 2014. Phoenix Arizona.

Results presented at the 2014 and 2015 Kansas State University Southwest Research-Extension Center near Garden City Field Days with more than 200 farmers and other agricultural sector stakeholders in attendance.

Students Trained:

Degree	**Student Name**	**Research Training**	**University/ Department**	**Complete Date**
Ph.D. Student	Tobias Oker	Trained on sensors and soil water monitoring for irrigation scheduling.	K-State BAE[1]	2017
Undergraduate Student/Summer Internship	Maria Calvillo	Trained in proper installation and use of soil water monitoring instruments such neutron probe and thermal infrared radiometers for canopy temperature monitoring	K-State, Natural Resources, and Environmental Sciences.	_

[1]Biological and Agricultural Engineering

Assessment of Deteriorating Water Quality in the Ogallala Aquifer and its Effect on Crops in Western Kansas

Basic Information

Title:	Assessment of Deteriorating Water Quality in the Ogallala Aquifer and its Effect on Crops in Western Kansas
Project Number:	2014KS172B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-001
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	None
Principal Investigators:	Jonathan P Aguilar, Isaya Kisekka, Danny H. Rogers, Aleksey Sheshukov

Publications

There are no publications.

Annual Report for
Kansas Water Resources Institute Project

ASSESSMENT OF DETERIORATING WATER QUALITY IN THE OGALLALA AQUIFER AND IT'S EFFECT ON CROPS IN WESTERN KANSAS

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Goals and Objectives

The overall goal of this project was to establish baseline information on the status of water quality of the Ogallala Aquifer as it relates to the major agricultural crops in the region. The project objectives were to 1) quantify the spatial extent of water quality deterioration in areas underlain by the Ogallala Aquifer, 2) evaluate the effect of varying concentrations of specific chemical constituents primarily chloride and sulfate on crop growth, and 3) encourage participation of a student in the field of water resources.

Study Activities

Planning and Survey: The project team started identifying and mapping all the center pivots that show signs of deteriorating water quality. The primary criterion was the presence of PVC pipes retrofitted below the main center pivot structure. Based on the accounts of irrigation dealers and some irrigators, putting a PVC underneath the main structure of the center pivot is one way of extending the life of the irrigation system by preventing further corrosion of the main pipe due to saline or highly corrosive water. These PVC retrofitted center pivots were initially very prevalent in the Arkansas River corridor in southwest Kansas, understandably because of the saline condition of the water in this river. However, in recent years, a noticeable number of these systems can be seen further south of the Arkansas River corridor. Our strategy was to drive around highways and county roads to map all PVC retrofitted center pivots in southwest Kansas then create a stratified sampling procedure to implement water quality testing on these wells.

To date, we were able to identify and map more than 225 of these PVC retrofitted center pivots with almost half of them located outside the Arkansas River corridor (Figure1). The analysis shows that many of these center pivots are adjacent to cattle feedlots that either are using the center pivots to apply the wastewater to an adjacent land or are having localized water quality issues. However, the most interesting observation is that many of these center pivots are clustering to at least three areas (e.g. northeast of Johnson City, border of Haskell and Grant counties along US Highway 160, and south of Sublette along US Highway 83) where there seems to be no obvious reasons of water quality issues. We have shown these clustering to the Groundwater Management District 3 (GMD3) and Kansas Division of Water Resources (DWR) personnel familiar with the area, and they seem to be surprised as well about the evident clustering.

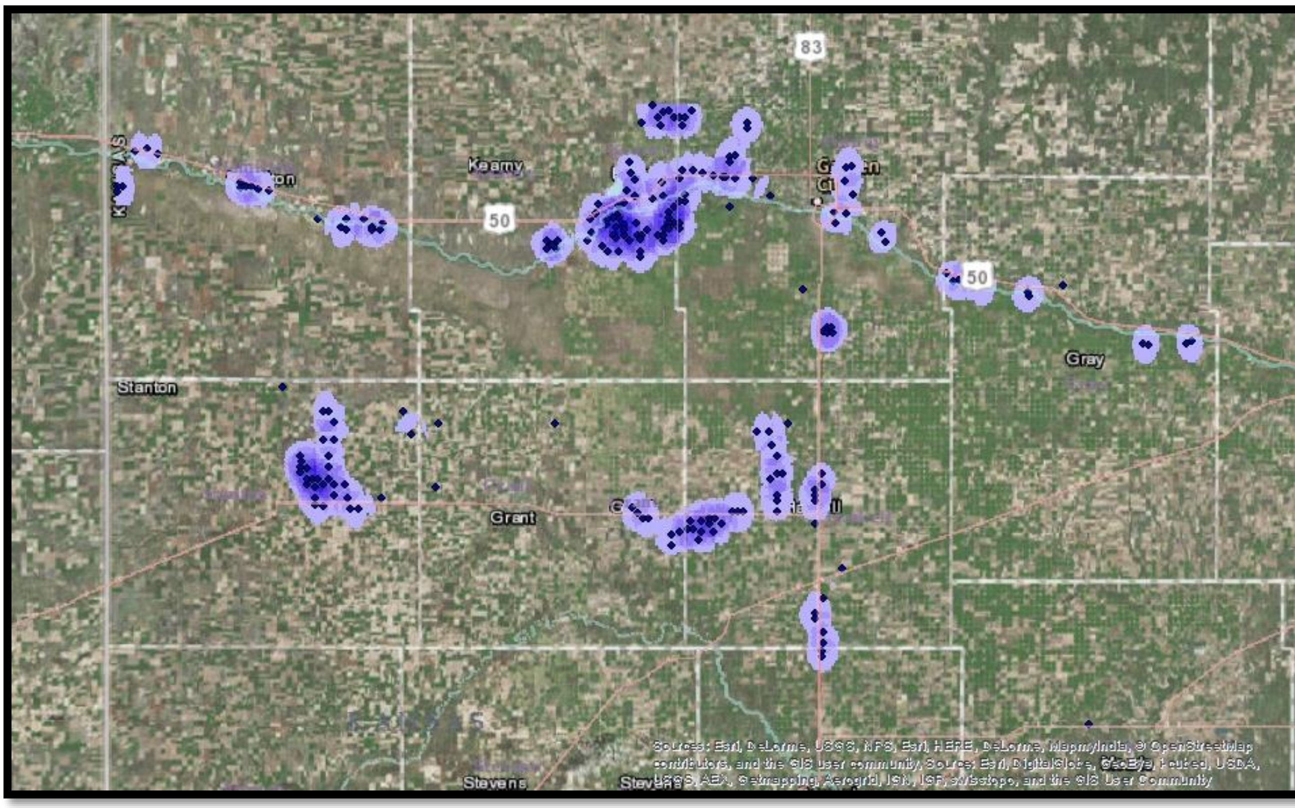

Figure 1. Location (dots) and density map (purple shade) of the PVC retrofitted center pivots across southwest Kansas as of March 2016.

Water Sampling and Analysis: One of the activities we initiated was a widespread dissemination and educations on the importance of water quality testing even on wells were water quality does not seem to be an issue. We collected samples from several wells and submitted them to a private laboratory, Servi-Tech for irrigation water quality analysis. One concrete positive result of our efforts was the establishment of a new program of the Garden City Company to encourage and collect yearly water quality testing on all the wells (around 50 wells) within their managed area. They contacted us and offered to share the database of these water quality tests from this year onwards. A summary of the water quality tests are shown in Table 1. Most of these wells are located within the Arkansas River corridor where majority of the PVC retrofitted center pivots could be found.

Based on the initial mapping results, we initiated strategic water quality sampling particularly in areas with clustering. Our sampling strategy was to collect water samples from the wells adjacent and within the clusters on a North-South and East-West transects. We have already identified the wells, but since these wells are privately owned, we have to seek permission from the registered owners to collect water samples. We started by querying the registered owners from the Kansas Department of Agriculture's online database called Water Information Management and Analysis System (WIMAS). However, WIMAS did not have updated and complete contact information of the well owners or water right holders to at least allow us to mail correspondence. We sought the help of Groundwater Management District 3, the local management district where all of the mapped are located, in getting the most recent mailing information of the well owners. It took several months for GMD3 to release the requested information.

We immediately sent out letters to the well owners explaining the purpose of the water sampling, survey, and project, in general. Enclosed in the letter was a stamped self-addressed postcard where the well owner would check (either Yes or No in the consent) and sign before mailing them back. As of writing of this report, we only received 10% of the consent postcards with 80% of them having affirmative permission. We will wait for a couple more weeks to send a follow-up letter and initiate the sampling process.

Table 1. Summary of water quality tests in the Arkansas River corridor.

Overall Rating	**No. of Wells**	**Average Langlier Index, at 20C**	**Average Electrical Conductivity, EC (μmho/cm)**	**Average Sulfate, SO4** (mg/L)	**Average Chloride, Cl** (mg/L)
Good	4	0.63	999	205	76
Acceptable	5	0.86	1,798	744	109
Fair	6	0.73	2,193	988	122
Poor	7	0.84	2,643	1,243	131
Very Poor	5	0.82	3,008	1,500	162
Total / Average	**27**	**0.79**	**2,211**	**988**	**123**

Plant Testing: At the start of the project, we geared up to test the response of some crops to different levels of electrical conductivity (EC) of water. However, late in the month of May 2014 we were informed that the greenhouse where we have set-up the experiment experienced a major problem in its cooling system. Apparently, it needs a major repair and could take several weeks before it could be restored. The other greenhouse in the station was damaged by a hailstorm on April 2014. The team decided to abandon this objective for several reasons. First, it was then too late to transfer the set-up to an outside plot since most crops have already been planted, and it will now be logistically difficult to carry out the experiment. Second, the student helper hired was only available until the end of July so the experiment would be difficult to finish in a timely manner. And third, since we might not have the same scenario as with the second year, the experiment would be difficult to justify as a true replication of each year. We have informed the overall coordinator, Dr. Dan Devlin, of these changes and offered to reallocate our resources to the other objectives.

Mapping and Geo-Statistical Analysis: After having mapped all the PVC retrofitted center pivots, we will perform the geostatistical analysis once we have the water quality test results from the wells.

A Success Story

Objective: Encourage participation of a student into the field of water resources. In the first year of the project, a student from the Garden City Community College (GCCC) was hired to work as summer student help. The student, Bruce Niere, was taking an Associate Degree in Graphic Designs and has very minimal experience in agriculture and water resource. While doing fieldwork, he usually asks questions regarding how crops are grown, how they respond to irrigation, and why water quality matters, among others. Throughout the summer, he gained appreciation of the importance of the research activities the water management program is conducting at the Southwest Research-Extension Center (SWREC).

On December 2014, he graduated from GCCC with honors. Mr. Niere then moved out from Garden City to work in Kansas City. Spring of 2015, I contacted him to see how he is doing and told him that we are again looking for students that could work for us over the summer. I was surprised when he expressed interest in the work. Recognizing his work ethics, flexibility in schedule over a student, and keen interest in agriculture and water resource research, I offered him a term position as Agricultural Technician. He quit his job in Kansas City to work for us full time in SWREC helping not only in this project but also in other irrigation projects and activities. He was involved in developing informational materials related to agriculture and water resources using his academic training on graphic design.

Recently, after taking a personal vacation and fulfilling the terms of his previous position (term positions could only be employed 999 hours within every 365 days), Mr. Niere went back to work for SWREC on a regular position as Agricultural Technician for the Water Management Program. In addition to the previous activities, he is now also involved in the technology development and maintenance activities of the program.

I consider this a fulfillment of the third objective of this project, encouraging participation of a student into the field of water resources. Mr. Niere made a significant shift in his career by not only going back to work with SWREC where he started as a student, but by utilizing his skills towards agriculture research and extension activities. I would not be surprised if he pursues his career further or take additional courses toward a higher degree now that he could see the relevance of his skills. I believe that though his passion is still graphic design, he is using talents and skills towards the field of water resources and agriculture, thus a success story for KWRI's overall goal.

Discussion

This project was very promising at the start. However, unforeseen challenges haunted the project activities throughout the two years. We were able to perform the field survey but were hampered by lack of updated contact information of well owners. Once we got the contact information and the consent letters sent, the response rate was not satisfactory despite efforts to exemplify the benefits and simplify the consent process.

On the positive side, the project has opened the avenue of conversation and realization that water quality issues exist in certain areas of southwest Kansas. The GMD3 and the Kansas DWR are now aware that special consideration has to be instituted in the areas where PVC retrofitted irrigation systems are clustered or prevalent. In addition, through the information dissemination activities, The Garden City Company has developed a program where they encourage the farmers within their managed area (around 28,000 acres) to regularly submit water quality tests. A database has been created and shared with SWREC (a summary is shown in Table 1). Results of this project will be used in further study of the water quality issues within the Ogallala Aquifer region.

Conclusion

Despite the challenges, the project was able to fulfill two of three objectives identified. However, once the consent from the well owners has been secured, the activities on water quality testing and geospatial analysis will be continued at no cost to the project, hoping to eventually fulfill all three objectives. We will continue mapping any additional PVC retrofitted center pivots that we may observe to build a database for this issue.

As indicated in the original project document, the information derived from this study will be shared in extension education meetings, experiment station field days and tours (see deliverables). Producers, policy makers, and water resource managers in the region will be apprised of the significant results in this study using different communication avenues. It is also expected that the results of this study will be pivotal information in future research initiatives regarding the water quality of the Ogallala Aquifer. A peer-reviewed journal article will be written based on this project.

Presentations and Information Dissemination Related to the Project

1. SW Research Advisory Committee Meeting, Garden City, KS– 8 Jan. 2015
2. Groundwater Management District 3 Board Meeting, Garden City, KS – 13 Aug. 2015
3. Irrigation Management Seminar, Hugoton, KS – 29 Oct. 2015
4. SW Research-Extension Center Field Day, Garden City, KS - 27 Aug. 2015
5. Radio Interviews – KIUL 1240 AM and KBUF 1030 AM

Assessing Natural Variability in Groundwater Surface Water Interactions

Basic Information

Title:	Assessing Natural Variability in Groundwater Surface Water Interactions
Project Number:	2014KS173B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Surface Water, None
Descriptors:	None
Principal Investigators:	Andrea Elizabeth Brookfield

Publications

There are no publications.

Assessing Natural Variability in Groundwater/Surface Water Interactions

Year 2 Progress Report

Andrea Brookfield, Principal Investigator, Kansas Geological Survey, andrea@kgs.ku.edu, 785-864-2199

Research Needs & Project Goals

The quantity and quality of any water resource can drastically change over both time and space. These changes can make effective water management a difficult task and can decrease the social, economic and environmental stability of the region. Over the past decade, the Great Plains region has experienced both severe drought and flood events, causing large variations in irrigation demand, soil moisture, groundwater recharge and surface water supplies in the region, exacerbating water management issues and increasing stress on local ecosystems. This uncertainty underscores the need to better understand how variability in climatic and hydrologic conditions affects the mechanisms that drive the spatial and temporal distribution of water.

The main goal of this research is to improve our understanding of groundwater/surface water (gw/sw) interactions and their temporal variations, and to determine the significance of these interactions for the distribution of water resources within the study area. To achieve this goal, we have established four specific objectives: 1) Automate the real-time collection of detailed data (stream stage, stream temperature, groundwater head, groundwater temperature and barometric pressure) for characterizing gw/sw interactions through time at three locations within Kansas; 2) develop methodology to systematically quantify gw/sw interactions using these data with a focus on water-level responses in shallow near-stream wells to stream stage changes; 3) analyze results to assess the relationship between temporal climatic and hydrologic variations and changes in gw/sw interactions; and 4) assess the role of gw/sw interactions in the distribution of water within the study area.

Methods

This study coupled groundwater sensors and surface water gages to monitor water levels in real time at three locations in Kansas (Figure 1). To effectively utilize existing infrastructure, all three sites had existing monitoring wells located close enough to a USGS stream gage to directly connect them or use low-cost radio transmitters to transmit the data from the well to the existing telemetry systems at the USGS gage stations. All wells originally were equipped with Instrumentation Northwest PT2X pressure and temperature sensors. In year 2, the sensors at two sites were replaced with Instrumentation Northwest CT2X pressure, conductivity and temperature sensors. Accessing the surface water and groundwater levels and temperatures from these gages is automated, and data are uploaded to dedicated KGS web pages for this study.

River Response Functions

The monitoring program was coupled with statistical data analysis methods to evaluate temporal changes in gw/sw interactions in response to climatic and hydrologic variability (e.g., Spane and Mackley, 2011). River Response Functions (RRFs) use a time-domain, multiple-regression convolution (superposition) method to assess the relationship between changes in groundwater level with changes in stream stage (Spane and Mackley, 2011). Response functions are determined using the regression convolution approach as outlined by Rasmussen and Crawford (1997). Assuming that water level changes in a well are only affected by changes in stream stage, the temporal changes in water levels are represented by the following equation:

$$\Delta W(t) = \sum_{i=0}^{m} \alpha_i \Delta S(t - i\Delta t) \quad (1)$$

where $\Delta W(t)$ is the change in water-level elevation in a well between time (t) and the time when the previous measurement was taken (t-Δt); $\Delta S(t$-$i\Delta t)$ is the change in stream stage between time t-$i\Delta t$ and the previous time when a measurement was taken [t-$(i+1)\Delta t$]; α_i is the unit response function at lag i; m is the maximum number of time lags for the hydraulic response; and Δt is the time between adjacent measurements (Spane and Mackley, 2011). As a general guideline, the unit response function (α_i) represents the impact of a change in stream stage on groundwater levels later in time; a large coefficient for a particular lag time ("i") indicates that a change in stream stage has a sizable impact on the change in groundwater level at time "i" after the stage change. Cumulative response functions (summing α_i through successive time lag steps) demonstrate the cumulative impact of a change in stream stage on groundwater levels (Spane and Mackley, 2011).

As previously mentioned, this method assumes that no other factors cause a change in groundwater levels except for a change in river stage. This assumption is reasonable in many river-alluvial aquifer systems where the river is the dominant driver of groundwater level changes. However, caution is needed when assessing environments where other factors may be present; all known factors should be incorporated into equation 1. Temporal changes in RRFs may indicate that an unaccounted factor is influencing groundwater levels because consistent well responses are expected with uniform hydraulic properties under both gaining and losing conditions throughout the year (Spane and Mackley, 2011). It is also possible that an unknown factor driving changes in groundwater levels has similar temporal trends as river stage fluctuations, and the RRFs will remain consistent. For example, the water level in another nearby surface water body, such as a detention pond or lake, may result in temporal variations similar to those influenced by river stage because many dominant drivers of surface water level, including precipitation and evaporation, are the same. In this work we investigated another method of assessing temporal trends in river-aquifer interactions, a variation of the RRF termed the Gradient Response Function (GRF). The GRF assesses the relationship between changing groundwater levels to changes to the hydraulic gradient between the river and groundwater.

Gradient Response Functions

As with groundwater flow between two points in the subsurface, the hydraulic gradient between the aquifer and surface water drives the direction and magnitude of flow between them, often represented by a first order equation akin to Darcy flux:

$$q_{sw-gw} = K_{sb} \frac{\Delta h}{\Delta l} \quad (2)$$

where $q_{sw\text{-}gw}$ is the flux from the surface water to the groundwater; K_{sb} is the hydraulic conductivity of the streambed material; and $\frac{\Delta h}{\Delta l}$ is the hydraulic gradient across the streambed interface, determined by:

$$\frac{\Delta h}{\Delta l} = \frac{h_{gw} - h_{sw}}{z_{gw} - z_{sw}} \quad (3)$$

where h is the hydraulic head and z is the elevation of the hydraulic head measurement points for the groundwater and surface water, denoted by subscripts *gw* and *sw* respectively. The use of elevation for Δl assumes vertical movement between the surface water and groundwater. Groundwater levels are not often measured directly below the streambed; however, this method assumes that the hydraulic head measured in the well is representative of that below the stream. Gaining rivers will therefore have lower hydraulic head, and losing rivers will have higher hydraulic head, compared to the underlying aquifer.

The GRF assess the relationship between changes in the hydraulic gradient between the river and the aquifer to water level changes in the aquifer. This method assumes a change in flux between the stream and aquifer (q_{sw-gw}) is the only factor contributing to changes in groundwater levels. This assumption does not hold under most conditions, but the temporal variability of response functions may provide insight into flow mechanisms between the river and aquifer.

Similar to RRFs, GRFs are determined using the regression convolution approach as outlined by Rasmussen and Crawford (1997). The temporal changes in hydraulic gradient are represented by:

$$\Delta W(t) = \sum_{i=0}^{m} \alpha_i \Delta G(t - i\Delta t) \quad (4)$$

where $\Delta G(t-i\Delta t)$ represents the changes in the hydraulic gradient between time $t-i\Delta t$ and the previous time when a measurement was taken [$t-(i+1)\Delta t$]. The regression equation used to determine the α_i terms also follows Butler et al. (2011) and is an ordinary least-squares linear regression. The gradient response plot (GRP) displays the cumulative response functions with respect to lag time and demonstrates the time-lag dependence of a change in well water level with a unit change in hydraulic gradient. As GRFs and RRFs use the same datasets and groundwater and surface water levels, there is no additional instrumentation or field effort required. While the GRFs are not robust enough to provide information about subsurface characterization or be used to remove the effects of stream stage from groundwater levels, compared to other response functions (e.g. Odling et al., 2015; Spane and Mackley, 2011), GRFs may provide further insight into the presence of other factors contributing to changes in groundwater levels, as demonstrated in this work.

We generated a series of aquifer/river response functions for each gage station based upon data collected for this study. From these functions, the temporal changes in fluxes across the gw/sw interface can be assessed by comparing how changes in water levels are distributed with time for each surface water perturbation. Furthermore, the functions developed for each site can be used for future projections of groundwater levels under variable surface water levels, as induced by changes to water management strategies and extreme hydrologic events.

Temperature-Based Flux Estimates

It was anticipated that a temperature-based estimation of gw/sw interactions would be calculated using the method outlined in Hatch et al., 2006. This method quantifies the changes in phase and amplitude of temperature variations between temperature sensors and uses these changes to estimate vertical fluxes between the two sensors. This method is well suited to this study as it is easily applied to large data sets and is independent of the absolute depth of the sensors, making it unaffected by streambed scour or sedimentation. This method is dependent solely on temporal variations in temperature and not stream stage or water level. As such, a comparison to all other analysis methods used in the proposed work would determine the sensitivity of this method to stream stage variability. As discussed below, site conditions did not allow this analysis to be completed.

Water Stable Isotopes

Water stable isotopes (^{2}H, ^{18}O) can be used to differentiate between rainwater, surface water and groundwater as the isotopic variations are based upon their time exposed to the atmosphere and, subsequently, evapotranspiration processes. Here, they are used to coarsely identify potential connections between surface water and groundwater and to provide a first order confirmation of RRF and GRF results. Samples for isotopic analysis ($\delta^{2}H$, $\delta^{18}O$) were collected in high density polyethylene (HDPE) bottles from surface waters as grab samples and from monitoring wells using a Geotech Geosquirt purge pump with low density polyethylene (LDPE) tubing. Wells were purged until pH, Eh, specific conductance, and temperature parameters stabilized. Samples were analyzed at the University of Kansas Keck Paleoenvironmental Stable

Isotope Laboratory on a Picarro™ L2120i cavity ring down spectrometer (CRDS) water isotope analyzer with an A0211 High Precision Vaporizor. Results are reported in the delta-per mil (δ-‰) notation, relative to the VSMOW (Vienna Standard Mean Ocean Water) standard. Deuterium data are considered accurate to 1‰ and $\delta^{18}O$ to 0.1‰.

Study Site Description

The study site is located along a portion of the Arkansas River in south-central Kansas from Larned to Nickerson. Three groundwater wells were coupled to existing surface water gages with telemetry in Larned, Great Bend and Nickerson (Figure 1). This river reach was chosen based on several factors, including having three locations with existing monitoring wells located close to USGS stream gages and significant variations in stream stage within a geographically small location. The river at Larned is generally dry, with flows only after intense precipitation events. The river at Great Bend and Nickerson is perennial with significantly higher flow at Nickerson compared to Great Bend (often an order of magnitude difference).

Study Results

Real-time data collection at all three sites was automated for stream stage and groundwater level. Data are transmitted to the USGS via a GOES satellite uplink, and the USGS has provided KGS access to this information. An automated data retrieval program was written to access the information and update an internal KGS database for all three sites every 2 hours. This information is made available via the KGS Stream-Aquifer Interactions web page (http://www.kgs.ku.edu/StreamAq/index.html).

In year 1, groundwater temperature was also transmitted from the Larned and Nickerson sites, and in year 2, the Nickerson site began transmitting electrical conductivity (EC) instead of temperature. Groundwater temperature was also logged and manually downloaded at the Nickerson site in year 2. Limitations on telemetry bandwidth did not allow for automatic groundwater temperature transmission at Great Bend, but the data are being logged and downloaded manually. Beginning in year 2, EC is measured in 15-minute intervals and transmitted every hour due to bandwidth restrictions at Great Bend. Onset Tidbits (http://www.onsetcomp.com/products/data-loggers/utbi-001) were deployed in June 2015 at all three stream locations during the second year to log stream temperature. However, due to intense summer precipitation events that caused high flows in the stream, the Tidbits were lost before data were downloaded. This, coupled with the muted groundwater temperature responses to river flow events, made it impossible to perform a temperature-based estimation of gw/sw interactions. Additionally, the limited EC measurements do not allow for analysis at this time, although initial measurements indicate results consistent with the statistical analyses. As Figure 3 illustrates, the EC at Nickerson is higher and more variable than EC at Great Bend. This may be indicative of the different groundwater recharge sources, although additional data are needed to confirm this.

River response plots (RRPs) and GRPs were developed and analyzed for Great Bend and Nickerson, following the methodology of Spane and Mackley (2011) and using a variation of KGS Barometric Response Function software (Bohling et al., 2011). Lack of consistent streamflow at Larned, and muted groundwater responses do not allow for response function analysis. Fifteen-minute lag times were used to match the frequency of water-level measurements, and visual analyses indicated that the groundwater response to stream stage fluctuations occurred within 1.5

days, or 150 lag periods. RRPs and GRPs were developed for identical 60-day intervals at both the Great Bend and Nickerson sites for comparison purposes.

Nickerson

Streamflow at the Nickerson site was an average estimated discharge of 275 cfs, and a minimum and maximum of 204 cfs and 624 cfs respectively, for the study period. Normalized RRPs for Nickerson (Figure 4a) indicate the initial and late response for all intervals are almost identical, with some variation through the middle lag periods. During the first two intervals (starting on 7/15/2014 and 9/12/2014 respectively), a dip in the response plot is evident between lag periods 35 and 95 (8.75 h and 23.75 h respectively). The presence of two peaks or bumps during these intervals indicate groundwater level changes that correlate with changes in the river stage, one early time and one late time, which are likely caused by two different mechanisms linked to the river stage. The mechanisms or pathways may be related to direct recharge from the river to the aquifer (early time), and to the river bank drainage after the river recedes or to recharge from the regional response to a precipitation event that also increased stream stage (late time). Future work will analyze RRPs at shorter intervals to better identify early and late time pathways.

The Nickerson GRPs indicate a consistent response across all intervals except three starting on 7/15/2014 and 8/28/2015 (Figure 4b). As opposed to the RRPs, these are the only times a dip is observed in the middle of the interval; further this dip is significantly less pronounced than those observed in the RRPs. The implications of which need to be further investigated with shorter term response function analysis, similar to that planned for RRPs.

Isotopic data collected from the Arkansas River and monitoring well at this site are quite similar (Table 1). Surface water and groundwater δ^2H and δ^{18}O values differed by a maximum of 7‰ and 1.4‰, respectively. Although these differences at this site are statistically significant, groundwater values (-39‰ to -44‰ and -6.6‰ to -6.7‰ for δ^2H and $\delta^{18}O$, respectively) are within the range observed for the Arkansas River at both Great Bend and Nickerson (-37‰ to -53‰ and -5.3‰ to -7.8‰ for δ^2H and $\delta^{18}O$, respectively). Thus, it is reasonable to conclude that groundwater and surface water are isotopically linked as suggested by the RRP and GRP, although a more intensive isotopic study is needed to further elucidate the nature and direction of the connection.

Great Bend

While streamflow is significantly lower at the Great Bend site compared to the Nickerson site, flow was still adequate to perform the response function analyses with an average estimated discharge of 50 cfs, and a minimum and maximum of 1.8 cfs and 1540 cfs respectively. The normalized RRPs for Great Bend indicate that three of the five intervals have nearly identical correlations between the river stage and groundwater (Figure 5a). The two intervals that do not match (consecutive intervals, starting on 11/9/2014 and 1/7/2015) have a strong positive lag coefficients for a short period, similar to those for Nickerson, followed by negative lag coefficients for the remainder of the interval. This may indicate that river stage changes during that time result in faster transmission of water from the stream to the aquifer. During this high river stage (due to the presence of a beaver dam a few feet downstream of the gage), water may have found other flow paths to reach the groundwater table. Previous research has demonstrated that beaver dams can influence groundwater-surface water interactions (e.g., Westbrook et al., 2006). As with the Nickerson RRPs, differentiating between pathways requires additional information.

More distinct variation is observed in Great Bend GRPs (Figure 5b) during the two consecutive 60-day intervals identified as outliers by the RRPs (starting on 11/9/2014 and 1/7/2015, respectively). In the GRP, it is clear that the lag coefficients are negative throughout most of the interval. This may indicate that the river is not the source of groundwater during this period, as an increase in potential flux between the river and aquifer (indicated by increasing hydraulic gradients) was apparently corresponding to a decrease in groundwater levels, or vice versa. During this 120-day period, the beaver dam (discussed above) increased water levels in the river. Despite the apparent relationship between groundwater levels and river stage when the beaver dam is not present, the discrepancy observed when it is present indicates there may be a source of water to the aquifer other than the Arkansas River. Further, the apparent relationship during most time periods indicates that events (i.e., precipitation and evaporation) may have similar effects on both the unknown source and the Arkansas River. The RRP for the 60-day period beginning on 9/8/2015 is consistent with RRPs that indicate a consistent groundwater response to a change in river stage (they both go up or down), yet the GRP clearly indicates that the groundwater response is not consistent with the change in hydraulic gradient, particularly at early time (Figure 5b). A site visit confirmed that a small beaver dam had been rebuilt. While the implications of GRPs are still relatively unknown, these results indicate that the GRPs may be more sensitive to anomalies in groundwater response to changes in river stage than RRPs.

In this work the presence of the beaver dam enabled identification of other possible factors contributing to changes in groundwater levels. There are many other causes of temporal variations in water levels could provide a similar opportunity to identify water sources. For example, seasonal variations in river water pumping for irrigation or periodic water discharge to the river from water treatment or industrial activities could create a unique trend in hydraulic gradient, allowing for analysis similar to that presented here. As environmental tracers, such as isotopes, use unique signatures of groundwater and surface water to identify water sources and pathways, groundwater responses to unique trends in hydraulic gradient may also be able to identify water sources and pathways.

Based on the RRP/GRP analysis that indicated another possible factor contributing to changing groundwater levels at the Great Bend site, further work was done to try to identify this factor. Several deep gravel pit/lakes are located near the Great Bend site, with the closest approximately 300 m west of the monitoring well. As water level data were not available from the nearby lakes to analyze the groundwater response to changing lake levels, water samples were collected from the river, monitoring well, and one lake at Great Bend for isotopic (δ^2H, $\delta^{18}O$) analysis to investigate these potential sources of water to the alluvial aquifer. Unlike at Nickerson, the groundwater isotopic composition (-5‰ to -13‰ and 0.5‰ to 1.2‰ for δ^2H and $\delta^{18}O$, respectively) was significantly higher than the range of values observed for the Arkansas River (-7.8‰ to -5.3‰ and -53‰ to -37‰ for δ^2H and $\delta^{18}O$, respectively). However, the isotopic composition of the nearby lake (-10‰ to -12‰ and -0.1‰ for δ^2H and $\delta^{18}O$, respectively) was quite similar to the groundwater. These data indicate that the lakes, may also contribute to groundwater levels at the Great Bend site (Table 1). All water samples for isotopic analysis at the Great Bend site were taken when the beaver dam was not in place, indicating that these isotopic conditions are not reliant on the beaver dam being present.

Discussion

For both the Nickerson and Great Bend sites, the response functions provide guidance for future work. At the Nickerson site, the response functions indicate periodic early- and late-time groundwater recharge mechanisms associated with changes in river stage. Future work will assess response functions for these events at shorter time intervals to try to interpret more information about the mechanisms. For the Great Bend site, inconsistent response functions when the beaver dam was present in the river indicated that there may be another factor contributing to changes in groundwater levels, leading to water stable isotope analyses of surface water from a nearby lake. These analyses provided a first-order confirmation of a source located in nearby lakes, although the lakes were located farther from the monitoring well than the Arkansas River. In addition to analyzing response functions with shorter time intervals, future studies at this site may also incorporate lake level measurements to confirm the connection to the aquifer. Groundwater and surface water temperatures were also measured at both sites; however, the magnitude of groundwater temperature response was not adequate to quantify interactions.

This work demonstrates the usefulness of several simple, inexpensive methods of delineating fluid flow pathways between a river and alluvial aquifer. Although the RRFs have been used previously to improve aquifer characterization (Spane and Mackley, 2011) and other response functions have been used to determine the vulnerability of aquifers (Odling et al., 2015), this work demonstrates the use of response functions as a preliminary tool to provide insight into groundwater/surface water interactions and guide future research efforts. The response functions for the Arkansas River indicated that the pathways between the river and alluvial aquifer differed between the Great Bend and Nickerson sites. Water levels at the Nickerson site had a temporally consistent response to changes in the stream stage, whereas there were temporal variations in water-level responses at Great Bend.

Information Transfer and Student Support

Two Master's students received summer funding as part of this work and were trained in geochemical sampling, sensor installation, isotopic analysis, river response functions, and numerical modeling. The results of the first year of this project were presented at the NovCare conference (http://www.ufz.de/novcare/) in Lawrence, Kansas, on May 19, 2015, and at the Governor's Conference on the Future of Water in Kansas in Manhattan, Kansas, on November 19, 2015. A manuscript was prepared to disseminate this research to the greater scientific community. It is undergoing internal review and will be submitted to Hydrogeology Journal.

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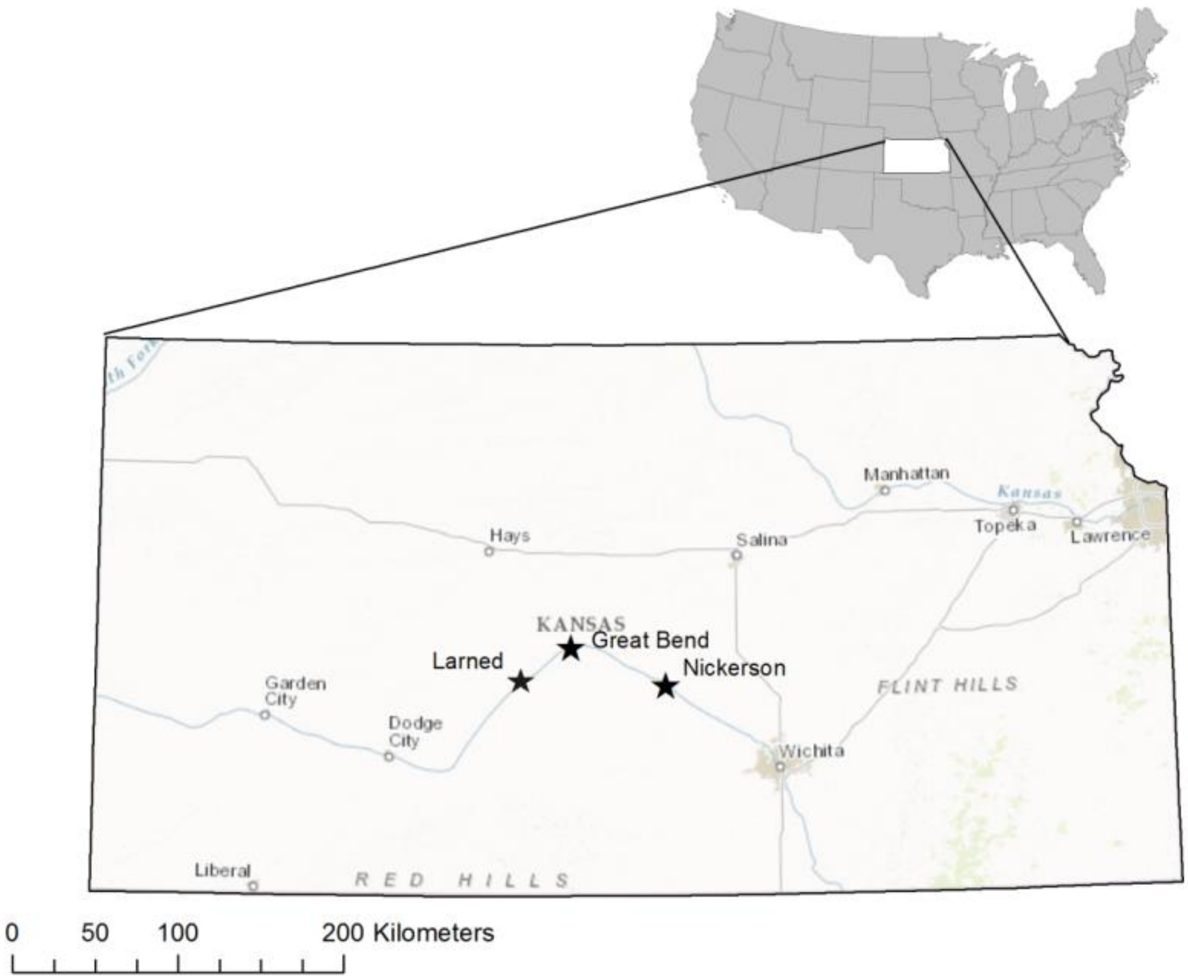
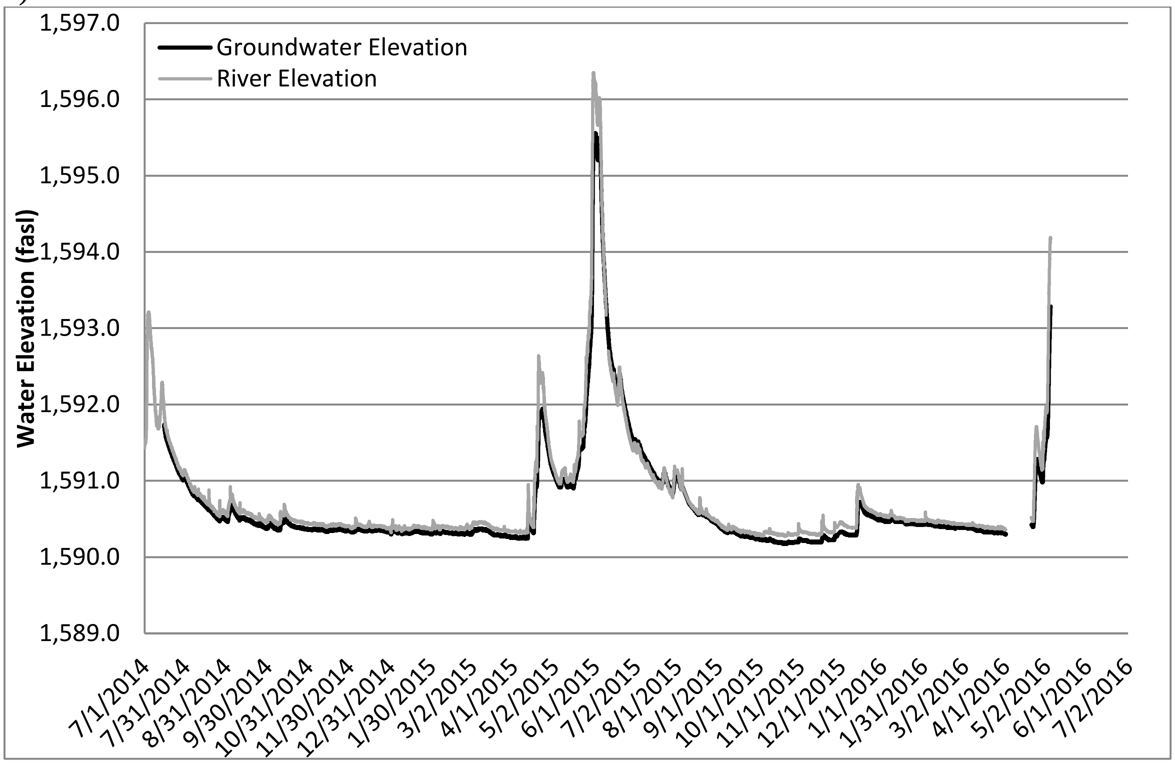


Figure 1 – Location of three USGS gages coupled to existing groundwater wells for this project.

a)



b)

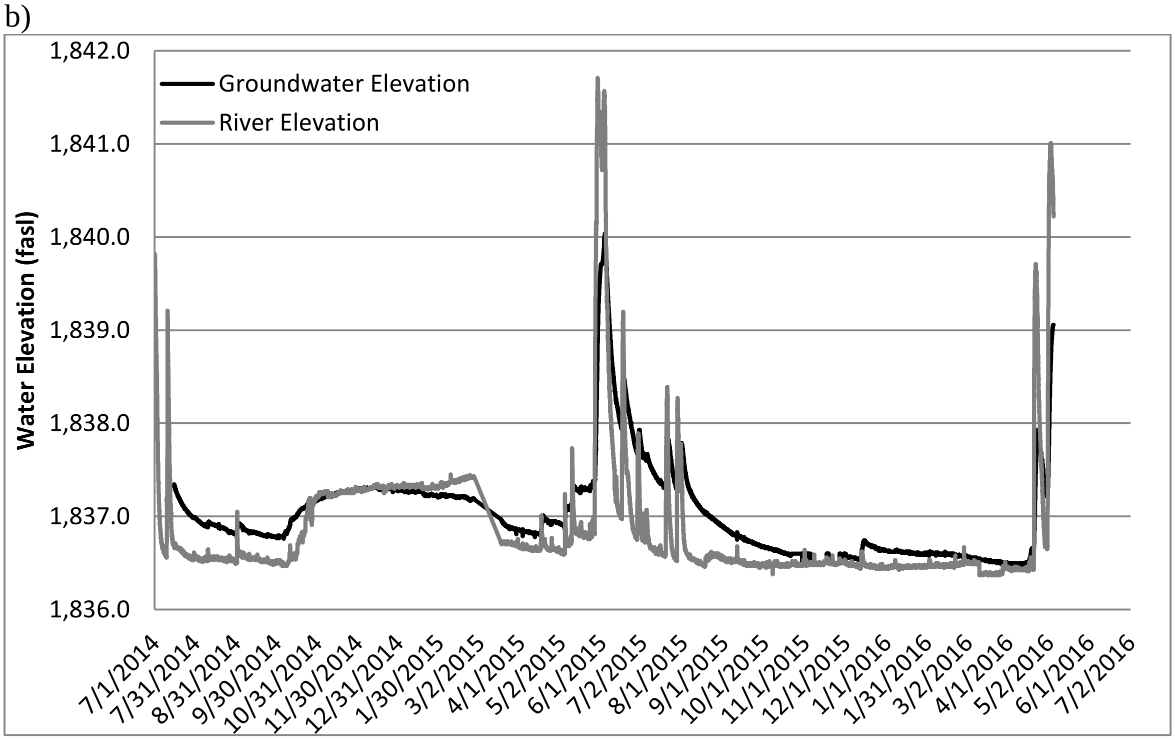


Figure 2 – Groundwater and surface water levels at a) Nickerson site and b) Great Bend site, throughout study period.

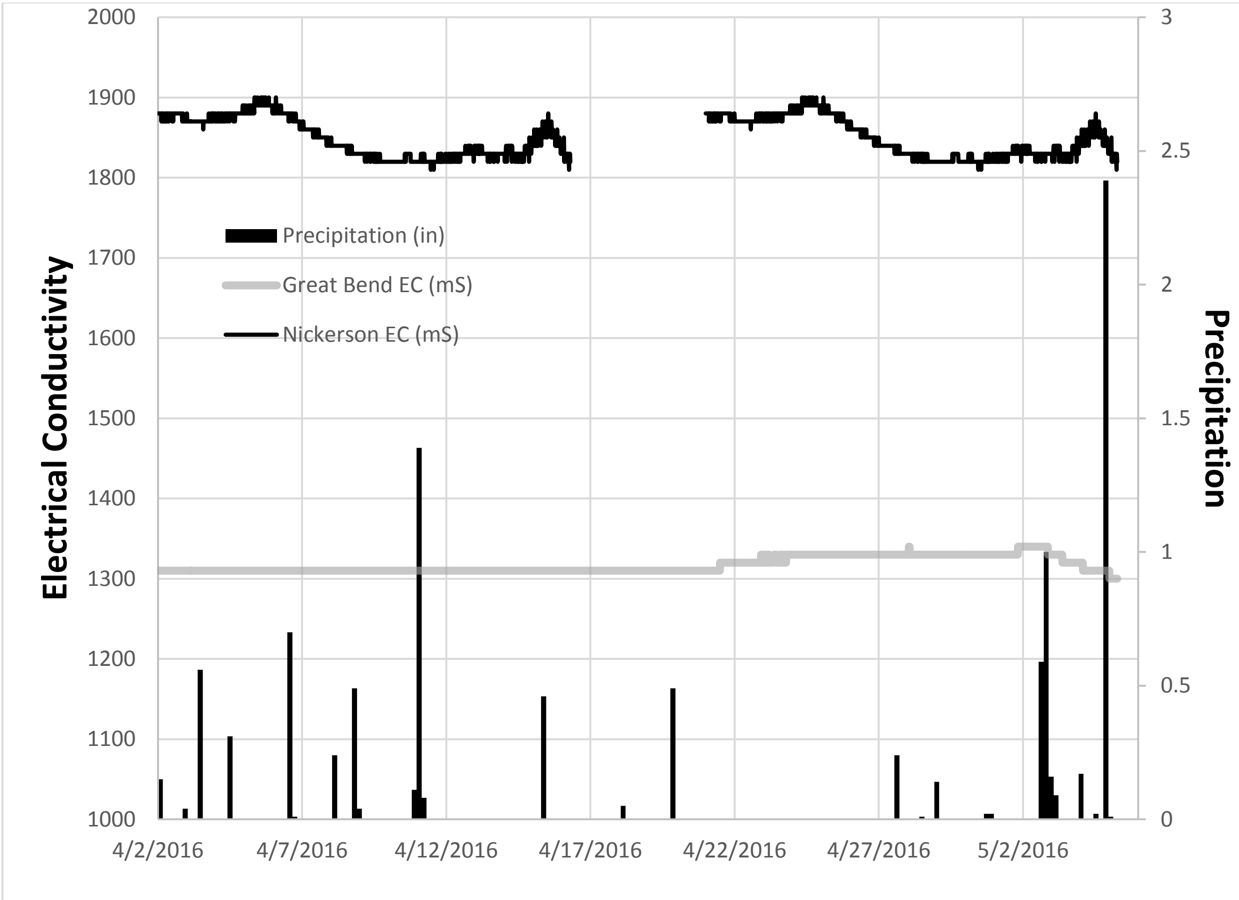
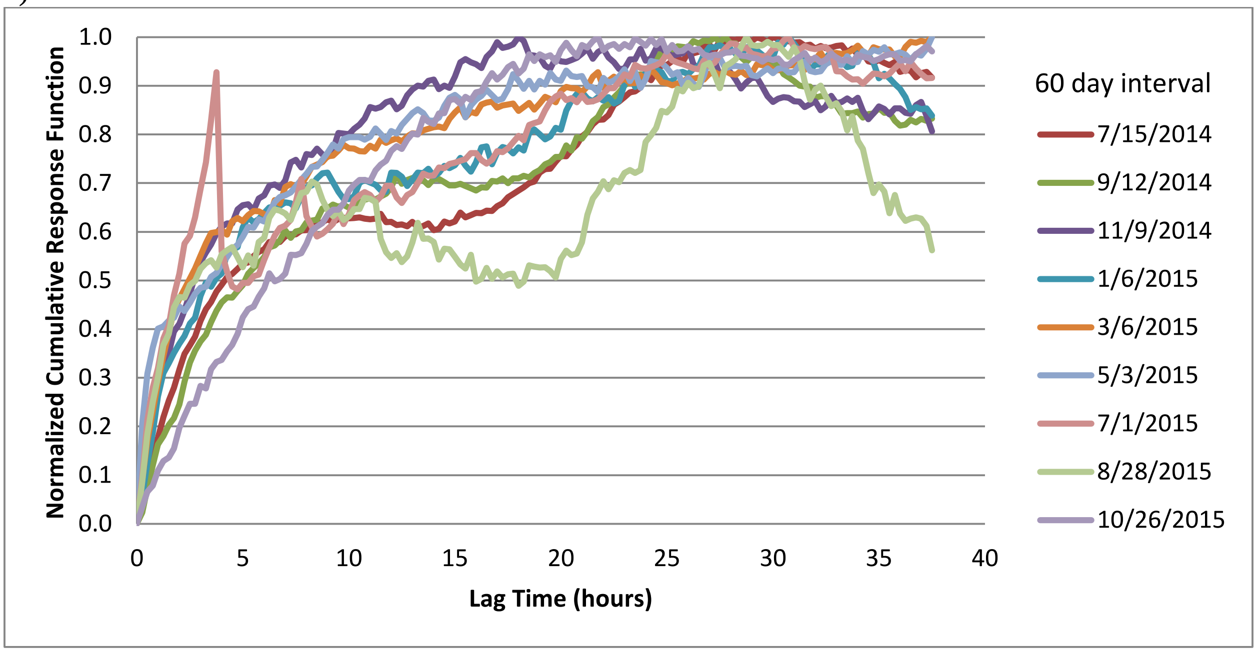


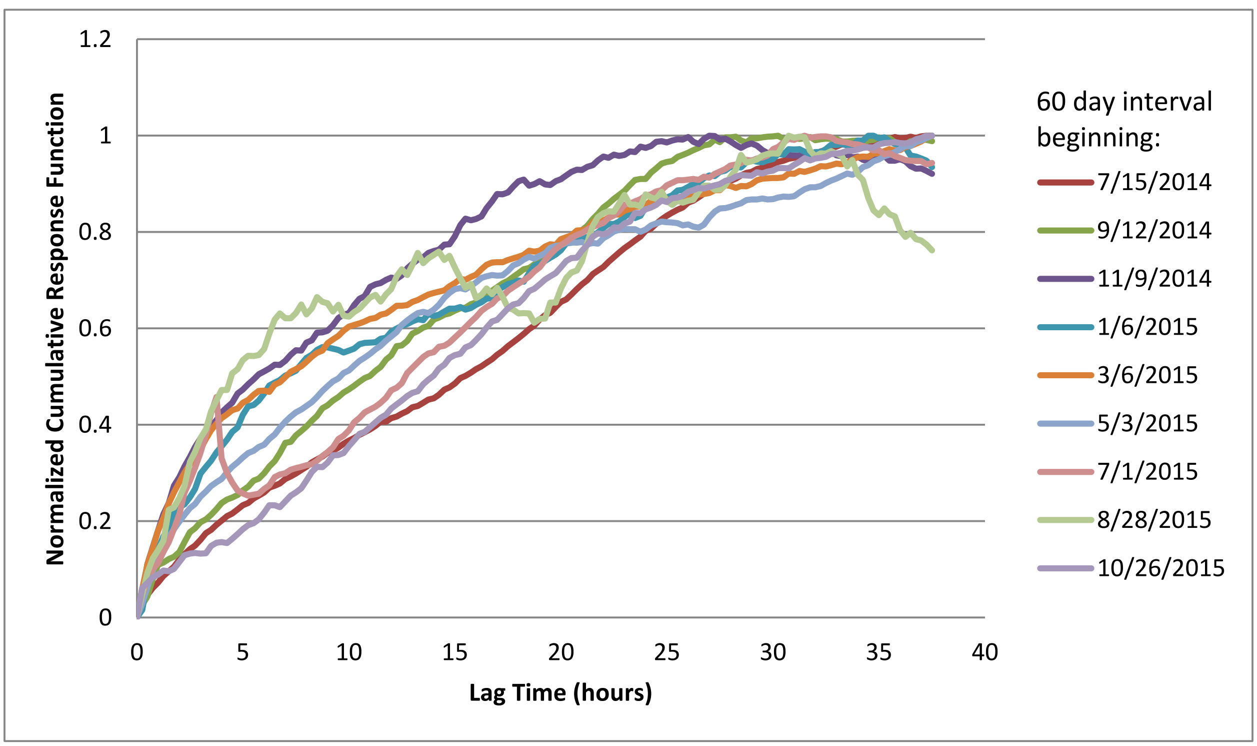
Figure 3 – Groundwater electrical conductivity measurements for the Nickerson and Great Bend sites and daily precipitation at Great Bend. Step in Nickerson EC measurements at the end of March of 2016 is hypothesized to be from a change sensor location within the well. Future work will confirm this hypothesis.

a)



Normalized Cumulative Response Function
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
35
40
Lag Time (hours)
60 day interval
7/15/2014
9/12/2014
11/9/2014
1/6/2015
3/6/2015
5/3/2015
7/1/2015
8/28/2015
10/26/2015

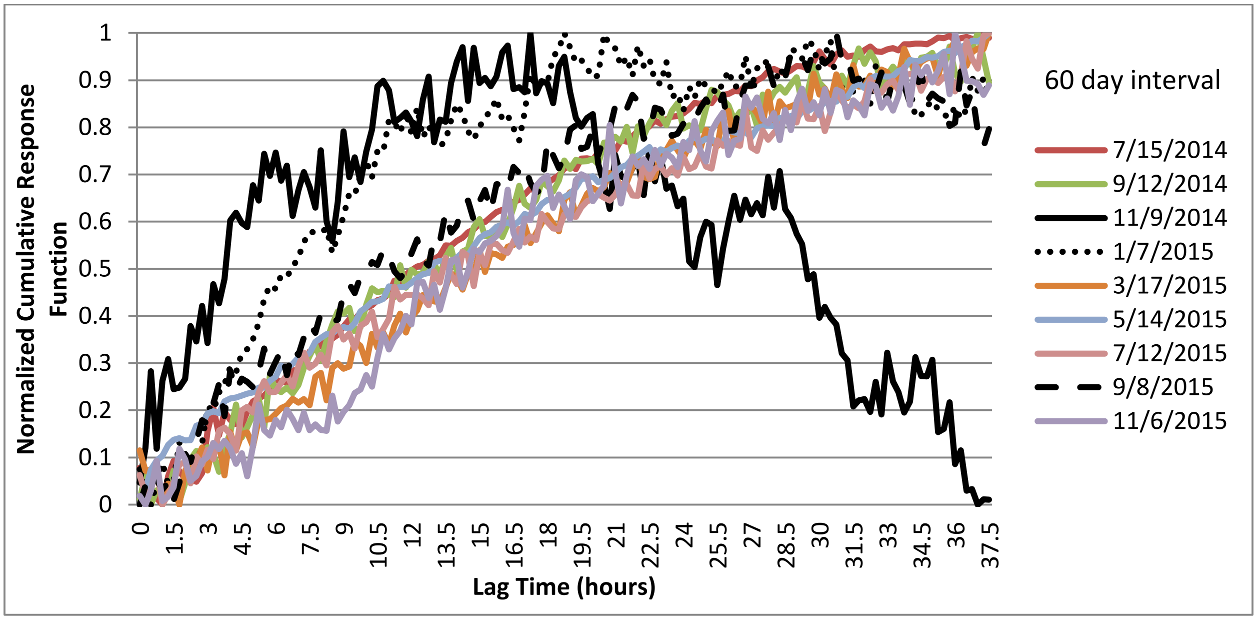
b)



Normalized Cumulative Response Function
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
Lag Time (hours)
60 day interval beginning:
7/15/2014
9/12/2014
11/9/2014
1/6/2015
3/6/2015
5/3/2015
7/1/2015
8/28/2015
10/26/2015

Figure 4 – Normalized a) river response plots (RRP) and b) gradient response plots (GRP) for the Nickerson site. Results are consistent between RRP and GRP analyses.

a)



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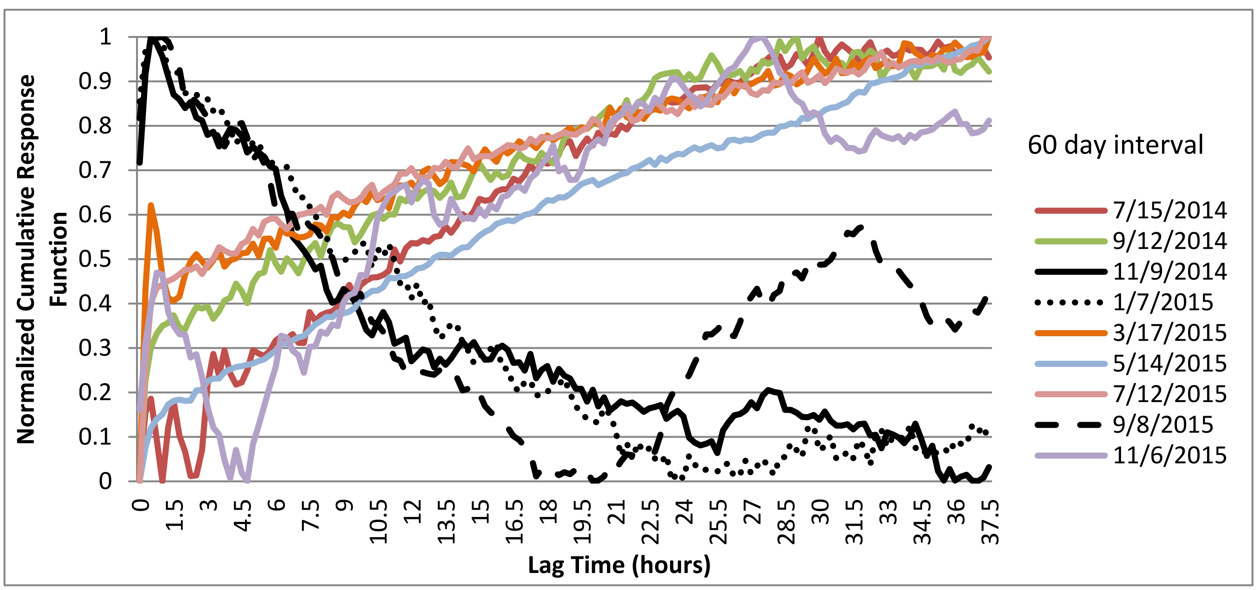

Figure 5 – Normalized a) river response plots (RRP) and b) gradient response plots (GRP) for Great Bend site. Dashed and dotted lines indicate 60-day intervals where the GRP and RRP results differ.

Table 1 – Isotopic analysis of groundwater, river water and pond water samples from the Arkansas River sites.

Site	Sample Date	Water Source	$\delta^{18}O$ V_{SMOW} (‰)	$\delta^{2}H$ $_{VSMOW}$ (‰)
Great Bend	July 17, 2014	Groundwater	1.2	-5.
		River	-6.0	-44
	June 9, 2015	Groundwater	0.5	-13.
		River	-7.8	-53.
		Lake	-0.1	-12
	June 23, 2015	Groundwater	0.6	-8.
		River	-6.7	-46
		Lake	-0.1	-10
Nickerson	July 17, 2014	Groundwater	-6.7	-44
		River	-5.3	-37
	June 9, 2015	Groundwater	-6.6	-39.
		River	-6.8	-45.

Fate of High Uranium in Saline Arkansas River Water in Southwest Kansas: Distribution in Soils, Crops, and Groundwater

Basic Information

Title:	Fate of High Uranium in Saline Arkansas River Water in Southwest Kansas: Distribution in Soils, Crops, and Groundwater
Project Number:	2014KS174B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-002
Research Category:	Ground-water Flow and Transport
Focus Category:	Toxic Substances, None, None
Descriptors:	None
Principal Investigators:	Donald Whittemore

Publication

1. Whittemore, D.O., Ueshima, M., Aguilar, J., G.L. Macpherson, and D. Fowle, 2015, Fate of high uranium in saline Arkansas River water in southwest Kansas: Distribution in soils, crops, and groundwater. Governor's Conference on Future of Water in Kansas, Manhattan, KS, abstract available at http://conferences.k-state.edu/govwater/sessions/concurrent-session-3/

Annual Report for
Kansas Water Resources Institute Project

FATE OF HIGH URANIUM IN SALINE ARKANSAS RIVER WATER IN SOUTHWEST KANSAS: DISTRIBUTION IN SOILS, CROPS, AND GROUNDWATER

May 16, 2016

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Project Goals and Objectives:

Goal

Determine the fate of high uranium concentration dissolved in saline Arkansas River water that is used for irrigation, and which contaminates groundwater used for irrigation, in the upper Arkansas River corridor in Kearny and Finney counties, southwest Kansas. The results from this project will be very valuable for assessing whether high concentrations of uranium in irrigation water in the study area and other areas of the U.S., such as the South Platte River in northeast Colorado and southwest Nebraska, could be preferentially concentrated in soils and crops. If the uranium is substantially concentrated in the parts of crop plants used for feeding livestock or humans, the results could have potentially substantial ramifications for agriculture in the region.

Objectives

1. Determine concentration of uranium in representative soils and crops, and in river water and groundwater within the area where Arkansas River water is diverted for irrigation in Kearny and Finney counties. The main question to be answered is whether the uranium dissolved in the river and groundwater used for irrigation is being preferentially accumulated in soils and/or bioaccumulated in parts of crop plants or if it primarily remains in irrigation return flow and is mainly leached to the groundwater.

2. Provide data that can be used for a more comprehensive study and proposal for greater funding to determine more specifically the fate and distribution of the uranium, especially if the results indicate substantial accumulation in soils and the parts of crops used for animal and human food.

Study Activities:

Location of Study Area

The study area includes the Arkansas River corridor in Kearny and Finney counties in southwest Kansas. The sites sampled in the study are in the portion of the Arkansas River in Kearny County where irrigation water has historically been and is currently diverted for irrigation, and the Arkansas River corridor in Kearny and Finney counties where crop fields have been historically and recently irrigated with the diverted river water and groundwater impacted by past seepage of diverted irrigation water. The study was discussed with the manager of Southwest Kansas Groundwater Management District No. 3 (GMD3) who assisted in communicating the study to irrigators, so that it would be easier for the co-PI in the project at the Southwest Research–Extension Center (SWREC) of Kansas State University at Garden City to find irrigators and farmers willing to have their irrigation wells, soils, and crops sampled and analyzed, considering that the focus of the study on uranium is a potentially sensitive issue. The agreement is that the specific locations of the soil, crop, and irrigation well sampling sites on privately owned farms will not be reported but that the data locations will be indicated by the general study area. One of the six field locations is on the research land of the SWREC in Finney County where one of the co-PIs on the study works. Thus, except for the Arkansas River water samples and the SWREC field and irrigation well, the county location is the smallest resolution that will be noted for location data in this report.

Description of Investigations

1. Sampling: The sampling design involved collecting samples of input irrigation water, soils, and plants from six selected irrigated fields where different crops are grown. The design provides for determining uranium and major constituent concentrations in both river water and groundwater, in two modes of occurrence of plant-available uranium from two depths of the soils, and in the grain or primary plant part for livestock or human consumption, the non-grain above ground parts of the plants, and the roots of the main crops.

a. Input waters (Table 1): Samples of Arkansas River water were collected at the headgate of the Amazon irrigation ditch in southwest Kearny County during the summers of 2014 and 2015 and at Deerfield in eastern Kearny County during the summer of 2015 when flows were higher than average and when river water was diverted via the canal and distribution ditches to irrigate crops. In 2014, this was during the period when Kansas called for water from Colorado such that ongoing summer releases from John Martin Reservoir in southeastern Colorado were allowed to reach Kansas in substantial quantity rather than being greatly reduced by diversion for irrigation downstream of the reservoir in Colorado. In 2015, sampling of the Arkansas River occurred during a high-flow event release of water from John Martin Reservoir due to filling of the reservoir from greater than normal precipitation and snow melt. These data supplement earlier samples of river water collected at different flows from the study area. Groundwater samples were collected from wells associated with five of the crop fields from which the soil and plant samples were obtained during 2014 and with all six fields in 2015 (one of the irrigation wells served different crops in two fields).

b. Soils (Table 2): Soil samples were collected at different locations and at two different depths (1-2 ft and 3-4 ft) at each of six fields at the end of the growing seasons of 2014 and 2015. The soils from each field and depth were sampled using a coring device and transported and stored in soil sample bags. The samples from the different locations from the same depth in a field were composited. A portion of the soil samples collected in 2015 was sent to Servi-Tech Laboratories in Dodge City, Kansas, for a standard soil analysis designed for agricultural applications.

c. Plants (Table 3): Two fields each of corn and soybean and one field each of sorghum and alfalfa were sampled in 2014 and three fields each of corn and one field each of soybean, sorghum, and alfalfa were sampled in 2015. Two separate areas of each crop field were sampled after the plants had matured before harvest. Complete plants of corn, soybean, and sorghum, and alfalfa were collected at different locations (except for alfalfa, which was collected at one location in 2014) in each of the six fields and composited, transported, and stored in large cloth plant sample bags that allow air drying of the sample. The corn and milo plants were divided into above ground (grain, stalk, leaves, cob/husk) and below ground (roots) plant parts in the field and placed in separate sample bags. The soybean and alfalfa plants were placed in the sample bags as complete above and below ground parts.

2. Procedures for preparing samples for analysis:

a. Waters: Water samples were filtered through 0.45 µm membrane filters. Aliquots for cation and uranium determination were acidified with nitric acid.

b. Soils: Soil samples were allowed to completely dry at laboratory room temperature. Approximately 100 g of the samples were disaggregated with a mortar and pestle, passed through a 2 mm mesh sieve, placed in a heavy paper sample container with lid, and allowed to further air dry. Two 10 g portions are weighted and each placed in two 250 mL glass Erlenmeyer flasks with glass stoppers. To one 10 g portion was added 100 mL of high purity deionized water; to the other portion was added 100 mL of 1.58 N nitric acid (1:10 dilution of concentrated nitric acid). The deionized water and nitric acid in each of the flasks was allowed to leach the soil for two days; during several hours on each of the two days, a sample shaker was used to agitate the soil and solution. Over 40 mL of each leach solution was poured from the flask into a plastic centrifuge tube and centrifuged. Approximately 37 mL of the supernatant solution from each centrifuge tube with deionized water leachate was extracted and filtered through a 0.45 µm membrane filter. A pipet was used to extract 30 mL of each filtered solution into a plastic tube and 0.6 mL of concentrated nitric acid was then added. Exactly 10 mL of the supernatant solution from each centrifuge tube with a nitric acid leachate was pipetted into a 50 mL glass volumetric flask and diluted to the mark with high purity deionized water. The sample was divided into two portions, one for cation concentration determination and the other for uranium concentration measurement. About 30 mL of the deionized water leach solution was also poured from the flask, centrifuged, and then filtered for use in determination of anions. The high purity deionized water extract represents the water soluble fraction of the soil and the acid extract represents that fraction containing carbonate minerals and readily soluble iron and manganese oxyhydroxides to which uranium could be chemically bound.

Table 1. Information for river water and groundwater samples collected from the study area. The characters C1, S1, M1, etc. in the sample site name refer to the crop field in Table 2 with which an irrigation well is associated.

KGS lab number	Sample site name	Sample source	County	Sample date	Sample time	River flow at Kendall gage, ft^3/sec
2014113	Amazon Ditch headgate	Arkansas River	Kearny	7/15/2014	-	235
2014114	Amazon Ditch headgate	Arkansas River	Kearny	7/25/2014	15:45	241
2014115	Amazon Ditch headgate	Arkansas River	Kearny	8/7/2014	11:45	354
2014116	Corn field C1 well[a]	Irrigation well water	Finney	10/7/2014	16:00	
2014117	Corn field C2 well	Irrigation well water	Kearny	9/8/2014	11:00	
2014118	Soybean S1 field well	Irrigation well water	Finney	9/4/2014	10:00	
2014119	Alfalfa A1 field well	Irrigation well water	Kearny	9/10/2014	15:45	
2014120	Sorghum M1 field well	Irrigation well water	Finney	10/22/2014	17:00	
2015035	Amazon Ditch headgate	Arkansas River	Kearny	8/3/2015	10:00	659
2015036	Deerfield	Arkansas River	Kearny	8/3/2015	10:58	655[b]
2015037	Deerfield (duplicate)	Arkansas River	Kearny	8/3/2015	11:00	655[b]
2015049	Corn field C3 well[a]	Irrigation well water	Finney	11/4/2015	11:30	
2015050	Corn field C4 well	Irrigation well water	Finney	11/4/2015	13:30	
2015051	Soybean S3 field well	Irrigation well water	Finney	11/4/2015	13:35	
2015052	Sorghum M2 and corn C5 fields well	Irrigation well water	Finney	11/4/2015	13:45	
2015053	Alfalfa A2 field well	Irrigation well water	Kearny	11/4/2015	14:15	

[a] Field at Southwest Research–Extension Center, KSU, Garden City. Samples 2014116 and 2015049 were collected from the same well.

[b] Flow at the Deerfield stream gage was 84 ft^3/sec.

Table 2. Information for soil samples collected from fields in the study area. Soil samples were only collected from the 1-2 ft depth in 2014 because the soil at the fields was too dry for the sampler to penetrate deeper; instead, two separate sets of soil samples were collected at each of the two different soybean fields (S1a and S1b, and S2a and S2b).

Field crop	Sample code	County	Soil sample (number of composite sample locations)		Soil sample date
			1–2 ft depth[a]	3–4 ft depth[a]	
Corn	C1	FI[b]	2	2	10/7/2014
Corn	C2	KE	3	3	9/29/2014
Soybean	S1a	FI	2	0	9/25/2014
Soybean	S1b	FI	2	0	9/25/2014
Soybean	S2a	KE	2	0	9/25/2014
Soybean	S2b	KE	2	0	9/25/2014
Sorghum	M1	FI	2	1	9/26/2014
Alfalfa	A1	KE	1	1	9/26/2014
Corn	C3	FI[a]	2	2	10/13/2015
Corn	C4	FI	2	2	10/14/2015
Corn	C5	FI	2	2	10/14/2015
Soybean	S3	FI	2	2	9/18/2015
Sorghum	M2	FI	2	2	10/13/2015
Alfalfa	A2	KE	2	2	10/13/2015

[a] The soil samples collected from the sorghum and alfalfa fields in 2014 were collected from 0–2 ft and 2–4 ft.
[b] Field at Southwest Research–Extension Center, KSU, Garden City

c. Plants: After the plant samples had thoroughly air dried in the cloth sample bags, above ground samples of corn and milo were divided into grain (kernels, seeds) and non-grain plant portions. Complete plant samples of soybean were divided into soybeans, non-bean above ground plant parts, and root portions. The complete plant sample of alfalfa was divided into above ground and root portions. Soil was removed from the plants and the plant portions rinsed with deionized water to remove remaining soil and dust, and the biomass samples were dried at about 85^{o} C in a drying oven for a few hours. Approximately 100 g representing each biomass sample were ground using a grain mill to a consistency of flour, passed through a 1 mm sieve, mixed, and placed in a heavy paper sample container. The samples were then dried overnight at 85 ºC before a portion was taken for digestion. Procedure No. 1 in the nitric acid digestion method for analyzing plant material by Zarcinas et al. (1987) was used. One gram of plant sample was added to a glass tube made to fit a block digester with temperature controller (Techne Model DG-1); 10 mL of concentrated nitric was then added to the tube and allowed to stand overnight at room temperature. The tube was first heated for 4 hr at 120 ºC in the block digester followed by heating at 140 ºC for a couple to a few days until about 1 to a few mL of acid solution remained. After cooling to room temperature, 50 mL of high purity deionized water was pipetted into the tube. Each of the sample solutions was divided into two portions, one for cation concentration determination and the other for uranium concentration measurement.

Table 3. Information for crop plant samples collected from fields in the study area.

Field crop	Sample code	County	Biomass sample (number of plants)			Biomass sample date
			Grain	Above ground non-grain	Roots	
Corn	C1	FI[a]	4	4	4	10/7/2014
Corn	C2	KE	4	4	4	9/29/2014
Soybean	S1	FI	4	4	4	9/25/2014
Soybean	S2	KE	4	4	4	9/25/2014
Sorghum	M1	FI	4	4	4	9/26/2014, 10/7/2014
Alfalfa	A1	KE	1	1	1	9/26/2014
Corn	C3	FI[a]	4	4	4	10/13/2015
Corn	C4	FI	4	4	4	10/13/2015
Corn	C5	FI	4	4	4	10/13/2015
Soybean	S3	FI	4	4	4	10/13/2015
Sorghum	M2	FI	4	4	4	10/13/2015
Alfalfa	A2	KE	0	4	4	10/13/2015

[a] Field at Southwest Research–Extension Center, KSU, Garden City

3. Analysis of waters and solutions at the KGS:

a. An automated titrimeter was used to determine the alkalinity (bicarbonate) concentration of river and groundwater samples.

b. Ion chromatography was used to determine the concentrations of anions (sulfate, chloride, nitrate, fluoride, and bromide) in river and groundwater samples and deionized water leachates of soils.

c. Inductively coupled plasma-optical emission spectroscopy was used to determine the concentrations of cations (calcium, magnesium, sodium, potassium, strontium) in the acidified portion (nitric acid) of all water samples, soil leachates, and plant digests.

d. Inductively coupled plasma-mass spectrometry (ICP-MS) was used to determine the concentration of uranium in an acidified portion (nitric acid) of all water samples, soil leachates, and plant digests. The instrument was a quadrupole ICP-MS (PQII+XS). Matrix-matched calibration standards, drift corrector solutions, and calibration-check solutions were prepared by diluting purchased certified single- and multi-stock solutions; blanks were distilled-deionized water with nitric acid at the same concentration as samples and standards. Matrices were different for the waters samples, soil sample extracts, and plant digests, so matrix-matched standards were designed for each sample type. Signal drift was corrected using a modification of the method by Cheatham et al. (1993). Best-fit calibration curves had r^2 values larger than 0.9999. Detection limits were calculated using the IUPAC method as described by Long and Windforner (1983). Unknown samples were run as three short-term replicates, and 40% of the samples were run as within-run replicates. Within-run replicates were usually within 5% of each other.

Results

River Water and Groundwater Chemistry

Sample information and chemical data for the river water and groundwater samples are in Tables 1 and 4, respectively. All of the waters are saline (greater than 1,000 mg/L total dissolved solids) except for the first sample of Arkansas River water collected in 2014. The constituent in greatest concentration in all of the water samples is sulfate. All sulfate concentrations exceeded the recommended level of 250 mg/L for public consumption of drinking water; the values ranged from 389 to 1,850 mg/L. Nitrate-N concentration was low in the Arkansas River water samples as has been observed for the river during the last couple of decades. Nitrate-N in all of the groundwaters was below the maximum contaminant level (MCL) of 10 mg/L, although one well water was very close to the MCL.

The uranium concentration range in the river waters is 12.0–24.5 µg/L. This is substantially lower than in typical low flows of the river, which usually contain a uranium concentration that appreciably exceeds the maximum contaminant level (MCL) of 30 µg/L for public consumption of drinking water (Whittemore and Petroske, 2011). The uranium concentration range is 25.3–102 µg/L for the groundwaters sampled from irrigation wells; uranium in five of the groundwater samples substantially exceeded the MCL, and was somewhat above the MCL in another sample. The uranium concentration of 102 µg/L is the highest yet observed for groundwaters in the Arkansas River corridor in southwest Kansas.

The uranium concentration in the river and groundwater samples collected in 2014 and 2015 for this study are generally well correlated with the sulfate concentration (Figure 1). Points for the samples of Arkansas River water collected at the Amazon headgate and at Deerfield in 2014 and 2015 are close to the linear regression (and its extension to lower sulfate concentration if plotted in Figure 1) for river waters collected during 2009-2012 (Whittemore and Petroske, 2011; Whittemore, unpublished; Kansas Department of Health and Environment stream monitoring program). Four of the 2014 and 2015 river water samples have lower sulfate and uranium concentrations than any of the 2009-2012 samples, reflecting dilution of Arkansas River water by substantial rainfall and snowmelt runoff that occurred in the summer during the period when releases from John Martin Reservoir were allowed to pass through to Kansas. Points for six of the irrigation well water samples collected in 2014 and 2015 for this study plot near the regression line for Arkansas River water. Points for the other four well waters lie substantially above the regression line for the Arkansas River as do points for samples from wells in the City of Lakin municipal wellfield in Kearny County. This indicates either a relatively high background concentration of uranium in the High Plains aquifer before contamination by infiltrating Arkansas River water from the river channel or irrigation ditches and laterals, concentration of uranium relative to sulfate levels in the return flow below irrigated fields (such as could be caused by a decrease in sulfate concentration by precipitation of gypsum in the soil), or both causes.

The degree of the concentration of uranium in different sample media relative to other constituents is represented in this report as the ratio of uranium to total cation concentration. The total cation concentration is used instead of sulfate for the ratio because sulfate is difficult to determine in the acid extracts of the soil samples and digests of the plant samples, whereas cations can easily be measured in the dilute acid solutions by inductively coupled plasma spectrophotometry. The mole ratios of uranium/total cation concentration (where total cations include calcium, magnesium, sodium, and potassium) is plotted versus sulfate concentration in Figure 2 to determine the range in the ratio for river waters and groundwaters of different salinity in the study area. The ratio is relatively constant with salinity (as represented by sulfate concentration) in Arkansas River waters. Groundwaters from municipal wells in Kearny County generally have uranium/cation ratios near or above the ratio for Arkansas River waters, whereas groundwaters from municipal wells in the Sand Hill well field in Finney County have ratios near or below the ratio for the Arkansas River. The uranium/cation ratio for six of the irrigation well samples at the fields sampled for soils and crop plants in the study area are similar to the ratio for Arkansas River water, whereas the other four have a ratio greater than for the river.

Uranium loads were estimated for the Arkansas River water at the location of the Amazon headgate for the time when samples were collected for this study. Irrigation ditch companies in southwest Kansas called for Arkansas River water from the John Martin Reservoir in Colorado to be allowed to enter Kansas in substantial quantity (above low flows and great enough for diversion in Kansas canals) from early July to early August in 2014. No flow occurred downstream in the Arkansas River at Deerfield (eastern Kearny County) during this period except for July 30, 2014 when flow averaged less than 0.5 ft^3 for that day that was caused by a rainstorm (USGS flow records, http://waterdata.usgs.gov/ks/nwis/current/?type=flow). During the sampling in 2015, high flow was being released from the John Martin Reservoir. Some of the water entering Kansas was diverted for irrigation. The flow was great enough to cause significant flow at Deerfield. However, no flow occurred downstream at Garden City during the summer of 2015 except for brief flows averaging a few to several ft^3 per day for about a day from runoff in the city after heavy rainstorms. Thus, all of the flow from Colorado that entered Kansas during early July to early August either seeped into the alluvial and High Plains aquifers underlying the riverbed or was diverted for irrigation. The estimated uranium load that either infiltrated into the subsurface, remained in soils, or that was taken up by crops during the couple months of high flow in 2014 was over 500 kg, which is equivalent to about 14,000 acre-ft of water with a uranium concentration of 30 µg/L, the MCL for uranium in public supplies of drinking water. The estimated uranium load for July through September 2015, based on the uranium concentration for the early August sample in Table 2 was roughly 2,400 kg, equivalent to 65,000 acre-ft of water with a uranium concentration at the MCL.

Table 4. Chemical data for river water and groundwater samples collected from the study area. See Table 1 for sample source, location, and date. The first three samples listed for 2014 (lab numbers 2014113-2014115) and 2015 (2015035-2015037) are from the Arkansas River; the rest of the samples are groundwaters from irrigation wells.

KGS lab number	Spec. cond., lab[a] µS/cm	pH, lab	SiO_2 mg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	B mg/L	HCO_3 mg/L	Cl mg/L	SO_4 mg/L	NO_3-N mg/L	F mg/L	Br mg/L	U µg/L	TDS[b] mg/L
2014113	1,092	7.67	9.64	96.5	34.7	84.9	12.3	1.49	0.15	163	29.4	389	1.41	0.53	0.13	12.0	746
2014114	1,625	7.77	10.8	138	60.2	149	8.70	2.41	0.24	207	45.3	686	0.21	0.70	0.23	19.1	1205
2014115	2,006	7.90	12.6	176	77.6	192	9.11	3.06	0.31	216	57.6	885	0.23	0.78	0.32	24.5	1521
2014116[c]	3,642	7.27	33.7	451	209	261	12.3	10.6	0.21	290	199.1	1,813	5.33	0.50	1.11	82.7	3157
2014117	1,989	7.84	25.7	295	70.1	83.3	8.15	3.92	0.15	201	101.5	854	5.58	0.32	0.68	26.6	1566
2014118	2,774	7.68	26.7	269	135	223	9.45	7.03	0.17	210	159.1	1,239	9.91	0.67	1.04	40.1	2217
2014119	3,585	7.29	29.5	371	185	363	13.6	10.2	0.40	343	128.6	1,818	0.72	0.55	0.85	102	3092
2014120	2,407	7.55	28.5	298	119	118	9.34	6.44	0.20	197	140.9	1,080	6.89	0.53	0.95	29.5	1931
2015035	1,662	8.06	14.1	147	64.1	154	8.15	2.38	0.41	232	46.7	653	0.35	0.94	0.24	16.3	1207
2015036	1,924	8.26	11.3	163	76.4	195	8.37	2.72	0.48	239	57.0	794	0.103	0.96	0.31	18.3	1428
2015037	1,929	8.27	11.4	165	76.4	194	8.44	2.72	0.49	240	56.8	793	0.082	0.95	0.31	18.1	1427
2015049[c]	3,698	7.35	34.0	423	205	268	15.1	9.66	0.14	289	193.7	1,851	5.31	0.33	1.15	79.9	3167
2015050	2,328	7.10	27.0	248	127	140	10.1	6.54	0.12	175	124.7	1,040	5.04	0.56	0.87	25.3	1832
2015051	2,385	7.20	27.5	230	117	189	9.93	5.79	0.12	201	103.6	1,043	6.66	0.54	0.76	32.4	1855
2015052	2,243	7.10	27.4	262	126	101	9.35	6.14	0.16	215	133.3	923	5.17	0.74	1.01	26.9	1719
2015053	3,225	7.20	29.3	335	173	258	14.2	8.61	0.32	407	145.3	1,452	3.45	0.31	1.28	67.0	2634

[a] Specific conductance at 25 ºC
[b] Total dissolved solids
[c] Samples 2014116 and 2015049 were collected from the same well.

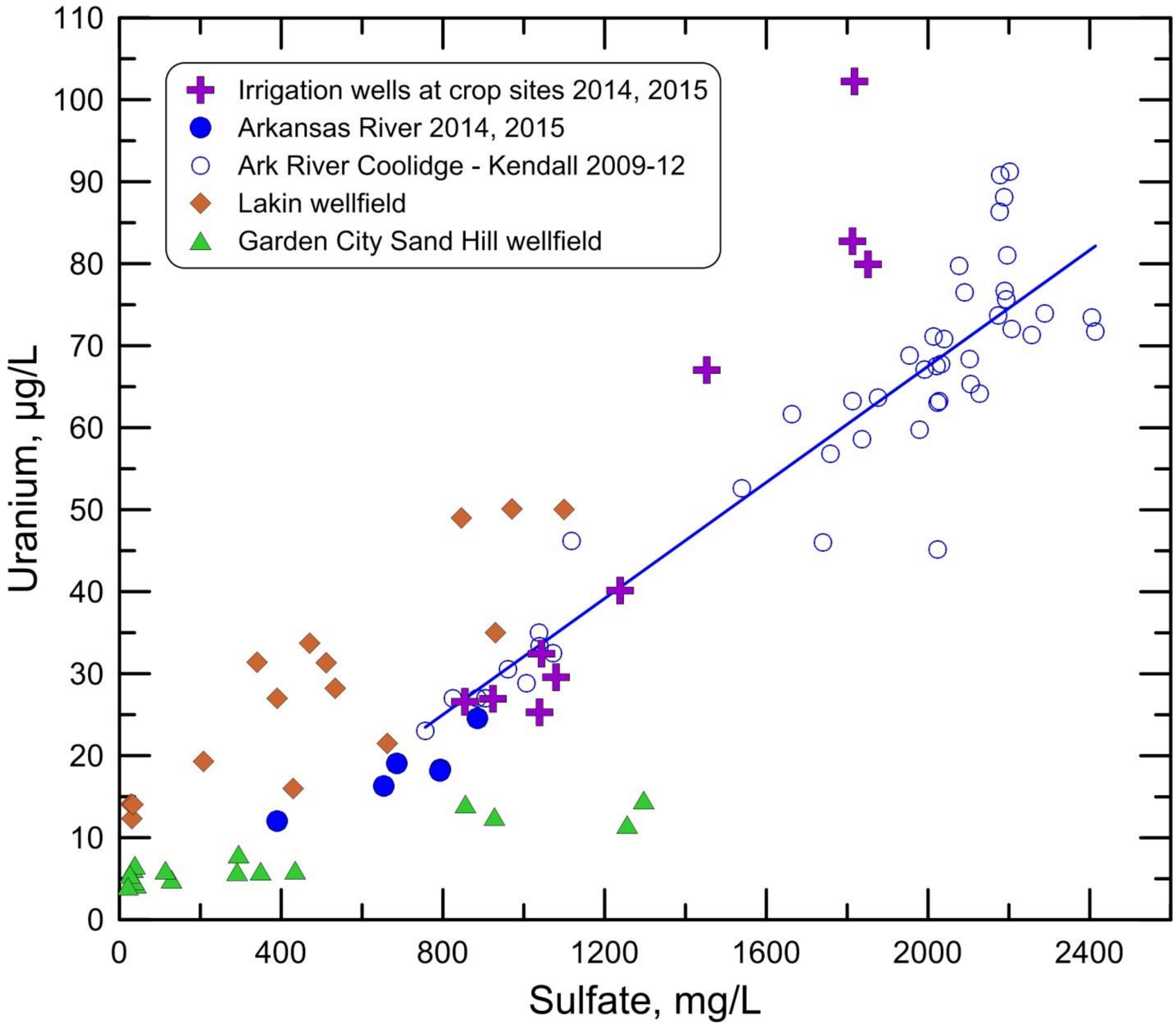

Figure 1. Uranium versus sulfate concentration for Arkansas River water collected from Coolidge to Deerfield and for groundwater collected from municipal wells in the City of Lakin wellfield in Kearny County and the City of Garden City Sand Hill wellfield in Finney County. The blue line is the linear regression for the points in the graph for Arkansas River samples collected during 2009-2012.

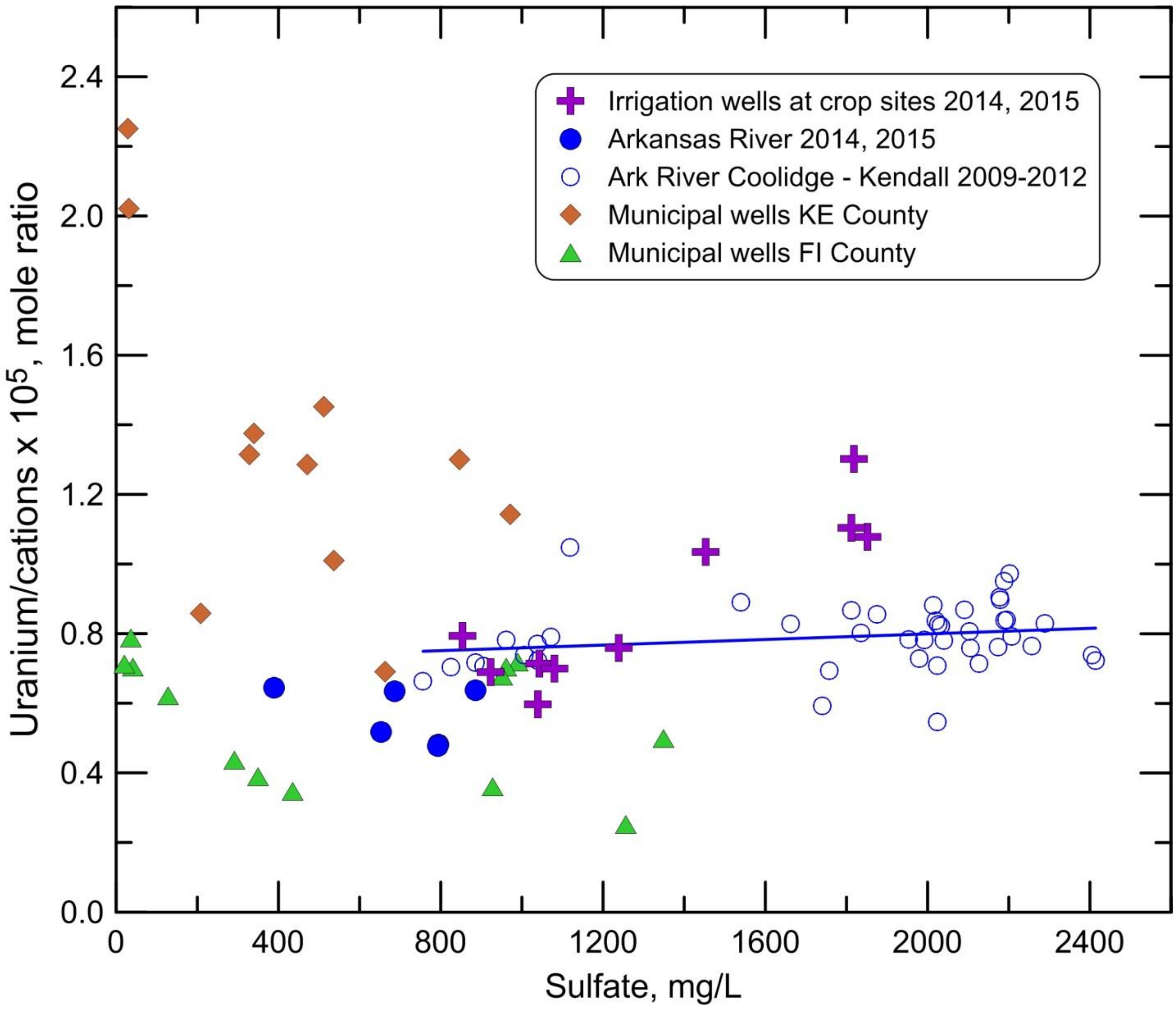

Figure 2. Mole ratio of the concentration of uranium to total cations versus sulfate concentration for Arkansas River water collected from Coolidge to the Amazon headgate and for groundwater collected from municipal wells in Kearny County and Finney counties.

<u>Soil Properties and Chemistry</u>

Physical and chemical properties of the soils collected in 2015 as analyzed using procedures (by Servi-Tech Laboratories) for agricultural applications are listed in Tables 5 and 6. The soils range from clay to clay loam to silty clay loam to silt loam to sandy clay loam; most are silty clay loam to silt loam (Table 5). The soils are saline, have a slightly alkaline pH, contain from 0.6% to 1.9% organic matter, and have a cation exchange capacity in the range 27-35 meq/100 g of soil. The constituents in order of decreasing concentration as determined in an ammonium acetate extraction were usually calcium, sulfate, magnesium, potassium, and sodium.

The order of decreasing concentration of major and minor constituents in the water extracts of the soils (Table 7) was usually sulfate, calcium, sodium, magnesium, potassium, nitrate, and strontium and fluoride. The deeper soil (3-4 ft) had mean concentrations (Table 8) of major constituents slightly greater than the shallower soil (1-2 ft), whereas the minor constituent concentrations were either about the same or slightly lower in the deeper than in the shallower soil. Uranium concentration ranged from about 3 µg/kg to 42 µg/kg of dry soil in the water extracts of the soils. The extracts for the deeper soils had a mean uranium slightly greater than that in the shallower soil but the difference is probably not significant.

Table 5. Physical properties of soils collected in 2015 (analyses by Servi-Tech Laboratories). Particle size analysis was by a hydrometer method. See Table 2 for the county location and sample date.

Field identification	Sample depth, ft	Textural classification	Sand, %	Silt, %	Clay, %
Corn C3 field, site 1	0 - 2	Silt Loam	21.4	52.4	26.2
Corn C3 field, site 1	3 - 4	Clay Loam	29.4	43.5	27.1
Corn C3 field, site 2	0 - 2	Loam	33.5	42.3	24.2
Corn C3 field, site 2	3 - 4	Silt Loam	23.6	52.3	24.1
Corn C4 field, site 1	0 - 2	Silty Clay Loam	17.8	50.9	31.3
Corn C4 field, site 1	3 - 4	Silt Loam	12.6	61.5	25.9
Corn C4 field, site 2	0 - 2	Silty Clay Loam	18.9	49.7	31.4
Corn C4 field, site 2	3 - 4	Silt Loam	22.9	56.1	21.0
Corn C5 field, site 1	0 - 2	Silty Clay Loam	18.7	50.8	30.5
Corn C5 field, site 1	3 - 4	Silt Loam	18.1	57.3	24.6
Corn C5 field, site 2	0 - 2	Silty Clay Loam	16.0	53.3	30.7
Corn C3 field, site 2	3 - 4	Silt Loam	19.8	57.3	22.9
Soybean S3 field, site 1	0 - 2	Sandy Clay Loam	58.1	12.0	29.9
Soybean S3 field, site 1	3 - 4	Silt Loam	9.4	63.9	26.7
Soybean S3 field, site 2	0 - 2	Silty Clay Loam	12.6	57.4	30.0
Soybean S3 field, site 2	3 - 4	Silt Loam	20.5	55.3	24.2
Sorghum M2 field, site 1	0 - 2	Clay Loam	21.7	45.8	32.5
Sorghum M2 field, site 1	3 - 4	Silty Clay Loam	13.5	53.0	33.5
Sorghum M2 field, site 2	0 - 2	Silty Clay Loam	16.3	51.8	31.9
Sorghum M2 field, site 2	3 - 4	Silt Loam	17.2	57.2	25.6
Alfalfa A2 field, site 1	0 - 2	Clay	22.7	32.7	44.6
Alfalfa A2 field, site 1	3 - 4	Clay	16.9	37.4	45.7
Alfalfa A2 field, site 2	0 - 2	Clay	16.5	38.3	45.2
Alfalfa A2 field, site 2	3 - 4	Silty Clay	<1.0	40.3	58.7

Table 6. Chemical properties of soils (analyses by Servi-Tech Laboratories). Cation concentrations and sulfur were determined using an ammonium acetate extraction. Sulfate was calculated for this report assuming the sulfur is present as sulfate.

Field identification	Sample depth, ft	Soil pH, 1:1 water-soil	Sp.C.[a], soluble salts, 1:1 water-soil, µS/cm	Organic matter, %	Cation exchange capacity, meq/100 g	NO3-N, mg/kg	P, mg/kg	Ca, mg/kg	Mg, mg/kg	Na, mg/kg	K, mg/kg	S, mg/kg	SO4, mg/kg
C3, site 1	0 - 2	8.0	1,490	0.9	33	7	6	5105	810	207	330	464	1,390
C3, site 1	3 - 4	7.9	1,290	1.3	31	7	9	4697	715	136	413	327	980
C3, site 2	0 - 2	7.8	1,250	1.0	27	5	7	4012	662	118	477	360	1,079
C3, site 2	3 - 4	8.1	1,400	0.7	31	10	12	4745	669	254	374	455	1,363
C4, site 1	0 - 2	8.0	1,300	1.2	34	4	9	5173	819	201	367	307	920
C4, site 1	3 - 4	7.9	2,170	0.9	35	10	10	5130	929	463	271	922	2,762
C4, site 2	0 - 2	7.8	1,050	1.3	32	7	11	4487	906	238	330	176	527
C4, site 2	3 - 4	7.9	1,480	0.6	35	7	11	5068	881	414	274	420	1,258
C5, site 1	0 - 2	7.8	1,400	1.3	33	8	8	4912	781	172	313	302	905
C5, site 1	3 - 4	7.9	1,310	0.9	32	8	7	4703	764	217	264	341	1,022
C5, site 2	0 - 2	7.9	1,740	1.1	35	7	6	5287	985	265	298	662	1,983
C5, site 2	3 - 4	7.9	1,690	0.6	33	32	7	4942	785	321	190	238	713
S2, site 1	0 - 2	7.8	1,560	1.4	33	3	7	4975	800	245	342	450	1,348
S2, site 1	3 - 4	7.9	1,960	0.7	34	2	10	5044	792	390	195	647	1,938
S2, site 2	0 - 2	7.9	1,150	1.4	32	3	14	4730	790	263	329	205	614
S2, site 2	3 - 4	8.0	1,250	0.7	31	<1	11	4688	743	294	208	299	896
M2, site 1	0 - 2	7.6	1,280	1.9	28	5	12	3784	865	166	491	296	887
M2, site 1	3 - 4	7.9	1,580	0.9	34	10	21	5428	875	245	305	371	1,112
M2, site 2	0 - 2	7.6	2,080	1.4	35	46	19	5125	961	274	415	592	1,774
M2, site 2	3 - 4	7.9	1,920	0.8	34	9	15	5108	839	367	272	468	1,402
A2, site 1	0 - 2	7.8	2,270	1.9	36	7	10	5419	1082	342	364	997	2,987
A2, site 1	3 - 4	7.8	2,630	1.5	37	2	11	5887	1097	577	274	871	2,610
A2, site 2	0 - 2	7.8	2,400	1.6	37	4	8	5571	1156	459	291	955	2,861
A2, site 2	3 - 4	7.8	2,940	1.6	39	2	9	8039	1291	619	306	3173	9,506

[a] Specific conductance at 25 ºC

Table 7. Constituent concentrations in deionized water extract of soils at two different depths. Concentration is for dry weight of soil. Soil samples from both soybean fields in 2014 were collected from different parts of the field (samples designated by a and b).

Crop field	Depth, ft	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg	Cl, mg/kg	SO4, mg/kg	NO3-N, mg/kg	F, mg/kg
2014 samples											
Corn C1	1-2	260	86.3	5.03	112	93.1	19.9	31.0	524	17.8	9.95
Corn C1 duplicate	1-2	329	108	6.12	111	96.1	27.1				
Corn C1	3-4	336	101	4.51	226	64.0	2.98	31.1	1,241	3.33	8.04
Corn C2	1-2	380	62.8	4.23	119	50.2	8.03	34.9	755	18.9	8.25
Corn C2	3-4	540	108	5.65	167	56.0	11.6	58.3	1,348	43.6	7.38
Soybean S1a	1-2	364	116	6.77	270	62.6	16.9	46.1	1,086	10.3	8.51
Soybean S1b	1-2	941	281	14.67	402	84.3	7.92	61.5	3,529	10.1	6.76
Soybean S2a	1-2	442	164	9.56	261	78.2	7.06	46.9	1,646	13.9	9.43
Soybean S2b	1-2	580	216	11.91	432	91.7	7.20	95.3	2,387	17.5	6.79
Sorghum M1	0-2	735	213	11.51	207	103.1	9.12	63.5	2,284	13.8	6.17
Sorghum M1	2-4	519	169	6.75	403	45.8	9.90	255	1,862	14.1	6.62
Alfalfa A1	0-2	1,299	409	26.33	966	62.7	36.8	64.3	2,849	4.58	4.70
Alfalfa A1	2-4	322	112	6.60	449	34.7	42.0	285	1,078	1.75	10.3
2015 samples											
Corn C3	1-2	519	176	8.75	161	63.3		49.7	1,838	10.1	9.07
Corn C3	3-4	640	197	8.18	214	67.3		35.3	2,349	9.75	7.82
Corn C4	1-2	435	170	7.45	200	33.5		26.3	1,215	14.1	13.4
Corn C4	3-4	339	130	4.93	217	21.0		43.2	3,781	8.36	9.64
Corn C5	1-2	373	137	6.91	199	34.7		28.7	1,601	10.5	9.22
Corn C5	3-4	891	307	12.59	453	45.2		156.1	1,214	15.0	9.78
Soybean S3	1-2	419	148	7.74	240	37.9		35.6	1,622	7.83	9.95
Soybean S3	3-4	472	183	8.57	326	24.6		53.0	2,233	0.57	8.74
Sorghum M2	1-2	719	245	11.46	259	56.5		109.0	2,477	34.9	8.44
Sorghum M2	3-4	706	229	8.93	333	38.8		204.0	2,588	14.3	10.0
Alfalfa A2	1-2	756	282	15.99	351	40.7		110.1	3,053	16.3	10.4
Alfalfa A2	3-4	1,552	455	20.78	652	62.7		148.1	5,814	4.17	8.92

Table 8. Ranges and means of constituent concentrations in deionized water extract of soils at two different depths. Concentration is for dry weight of soil. Uranium determination in the 2015 samples is currently in progress but the results were not available at the time of this report.

Crop field	Depth, ft	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg	Cl, mg/kg	SO4, mg/kg	NO3-N, mg/kg	F, mg/kg
Range 2014	1-2	260-1,300	62.8-409	4.23-26.3	111-966	50.2-103	7.06-36.8	31.0-95.3	524-3,530	4.56-18.9	4.70-9.95
Range 2015	1-2	373-756	137-282	6.91-16.0	161-351	33.5-63.3		26.3-110	1,210-3,050	7.83-34.9	8.4-13.4
Range 2014	3-4	322-540	101-169	4.51-6.75	167-449	34.7-64.0	2.98-42.0	31.1-285	1,080-1,860	1.75-43.6	6.62-10.3
Range 2015	3-4	339-1,550	130-455	4.93-20.8	214-652	21.0-67.3		35.3-204	1,210-5,810	0.57-15.0	7.82-10.0
Mean 2014	1-2	592	184	10.68	320	80.2	15.6	55.4	1,882	13.3	7.57
Mean 2015	1-2	537	193	9.72	235	44.4		59.9	1,968	15.6	10.1
Mean 2014	3-4	429	122	5.88	311	50.1	16.6	157	1,382	15.7	8.09
Mean 2015	3-4	767	250	10.66	366	43.3		107	2,997	8.69	9.16
Mean 2014, 2015	1-2	564	189	10.20	278	62.3		57.7	1,925	14.5	8.82
Mean 2014, 2015	3-4	598	186	8.27	339	46.7		132	2,189	12.2	8.62
Mean 2014, 2015	All	581	187	9.23	308	54.5		94.8	2,057	13.3	8.72

The order of decreasing concentration of major and minor cations in the acid extracts of the soils was calcium, magnesium, potassium, sodium, and strontium (Table 9). The deeper soil (3-4 ft) had mean concentrations (Table 10) of calcium, magnesium, and sodium that were greater than in the shallower soil (1-2 ft); the concentrations of strontium and potassium were about the same at the two soil depths. Uranium concentration ranged from about 0.6 mg/L to 1.5 mg/L in the water extracts of the soils. The extracts for the shallower soils had a mean uranium slightly greater than that in the deeper soil but the difference is probably not significant.

Table 9. Constituent concentrations in dilute nitric acid extract of soils at two different depths. Concentration is for dry weight of soil. Soil samples from both soybean fields in 2014 were collected from different parts of the field (samples designated by a and b). Uranium determination in the 2015 soil samples is currently in progress but the results were not available at the time of this report.

Crop field	Depth, ft	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, mg/kg
2014 samples							
Corn C1	1-2	8,047	2,098	81.0	118	1,300	1.12
Corn C1 dup.	1-2	7,484	2,811	82.8	118	1,746	1.18
Corn C1	3-4	36,795	3,528	96.1	277	1,222	0.609
Corn C2	1-2	19,522	2,603	86.1	136	1,326	0.778
Corn C2	3-4	35,131	3,631	97.1	214	1,283	0.882
Soybean S1a	1-2	28,129	3,810	118.4	330	1,339	1.15
Soybean S1b	1-2	24,982	3,706	115.5	469	1,464	1.07
Soybean S2a	1-2	4,761	2,562	92.6	292	1,427	0.935
Soybean S2b	1-2	5,705	2,889	99.0	475	1,597	1.03
Sorghum M1	0-2	24,309	3,335	93.1	488	1,232	0.799
Sorghum M1	2-4	7,090	2,634	92.1	223	1,410	0.838
Alfalfa A1	0-2	21,276	2,792	126.9	1,044	1,017	1.54
Alfalfa A1	2-4	21,473	2,836	95.8	525	1,057	1.06
2015 samples							
Corn C3	1-2	23,281	2,700	91.0	249	1,065	
Corn C3	3-4	34,673	3,091	94.8	335	1,239	
Corn C4	1-2	21,290	2,832	101.9	294	989	
Corn C4	3-4	37,752	3,853	109.0	644	1,168	
Corn C5	1-2	36,582	3,102	105.4	324	1,065	
Corn C5	3-4	35,864	3,492	95.4	620	1,074	
Soybean S3	1-2	27,017	2,911	112.7	373	1,060	
Soybean S3	3-4	43,037	3,734	121.0	578	1,077	
Sorghum M2	1-2	13,029	2,784	98.7	309	1,045	
Sorghum M2	3-4	41,914	3,898	101.2	539	1,272	
Alfalfa A2	1-2	33,839	3,363	197.9	524	1,018	
Alfalfa A2	3-4	38,950	3,719	198.9	813	1,097	

Concentrations of most cations and uranium were much higher in the dilute nitric acid extracts of the soils (Table 9) than in the water extracts. Mean calcium, magnesium, strontium, and potassium concentrations in the acid extracts were approximately 46, 17, 12, and 22 times those in the water extracts, respectively. The large increase in calcium is expected primarily from the dissolution of soluble calcium carbonate in the soil. The mean sodium content of the acid extract was only about 1.4 times that in the water extract, indicating that most of the available sodium was readily soluble in water. The larger potassium concentration in the acid extract than in the water extract could be related to cation exchange of hydronium ion from the acid for potassium on soil clays. The mean uranium concentration in the dilute acid extracts (in mg/kg in Table 8) was over 60 times that in the water extracts (in µg/kg in Table 7). The mode of occurrence of the uranium released during the acid extraction is expected to be largely adsorption on oxyhydroxides, primarily ferric oxyhydroxides, but also adsorption on other minerals such as clays.

Table 10. Ranges and means of constituent concentrations in dilute nitric acid extract of soils at two different depths. Concentration is for dry weight of soil.

	Depth, ft	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, mg/kg
Range 2014	1-2	4,760-28,100	2,100-3,810	81.0-127	118-1,040	1,020-1,750	0.78-1.54
Range 2015	1-2	13,000-36,600	2,700-3,360	91.0-198	249-524	989-1,070	
Range 2014	3-4	7,090-36,600	2,630-3,630	92.1-97.1	214-525	1060-1,410	0.61-1.06
Range 2015	3-4	34,700-43,000	3,090-3,900	94.8-199	335-813	1,074-1,272	
Mean 2014	1-2	16,024	2,956	99.5	385	1,383	1.07
Mean 2015	1-2	25,840	2,949	117.9	345	1,040	
Mean 2014	3-4	25,122	3,157	95.3	310	1,243	0.846
Mean 2015	3-4	38,698	3,631	120.1	588	1,155	
Mean 2014, 2015	1-2	19,950	2,953	106.9	369	1,246	
Mean 2014, 2015	3-4	33,268	3,441	110.1	477	1,190	
Mean 2014, 2015	All	26,609	3,197	109	423	1,218	

Crop Plants Chemistry

In general, the contents of major metals in the plant digests were higher in the beans and above ground non-grain plant material of soybean than those in the grain and non-grain material of corn and sorghum; concentrations in the roots of corn, soybean, and sorghum were roughly comparable (Tables 11-15). The metal in highest concentration in the plant digests was potassium. Potassium concentration in the grain of corn and sorghum was much lower than that in the above ground non-grain plant material of these crops, and also lower than in the roots. Potassium content in the beans of soybean was about the same as that in the non-grain plant material but higher than in the roots. Calcium concentrations in the grain of corn, soybean, and sorghum were much lower than in the above ground non-grain plant material; calcium was also lower in the grain of corn and sorghum than in the roots. However, calcium content in corn grain was about the same as in the roots. Magnesium concentrations in the grain of corn were lower than in the non-grain material and the roots, and in the grain of soybean and sorghum were lower than in the non-grain material but higher than in the roots. The mean contents of all major metals except sodium in the above ground plant material of alfalfa were greater than those in the roots.

Uranium contents in the digests of the grain of corn, soybean, and sorghum were less than 10 mg/kg; the approximate range was 0.5-3 mg/kg (Tables 11-15). Uranium was a little higher in the bean of soybean than in corn and sorghum grain. The uranium concentration in the grain of these crops was much lower than in the above ground non-plant material, which, in turn, contained a much lower content than in the roots. The mean uranium content of non-grain plant material in corn (87 mg/kg) was lower than that in soybean (154 mg/kg) but higher than that in sorghum (53 mg/kg). The mean uranium content of the above ground plant material of alfalfa (140 mg/kg) was close to that in soybean but higher than in corn and sorghum. The mean uranium concentration in the roots of corn (635 mg/kg) was lower than that in soybean (890 mg/kg) and the above ground plant of alfalfa (718 mg/kg), but higher than that in sorghum (428 mg/kg). The ratio of the mean uranium concentration in the roots to that in the non-grain above ground plant material ranged from about 7 for corn, to about 6 for soybean, 8 for sorghum, and 5 for alfalfa. The ratio of the mean uranium concentration in the non-grain material to that in the grain ranged from over 100 for corn to about 60 for soybean and 50 for sorghum. The ratio of the mean uranium concentration in the roots to that in the grain ranged from nearly 800 for corn to about 360 for soybean and nearly 400 for sorghum.

Table 11. Constituent concentrations in nitric acid digest of plant samples. Concentration is for dry weight of plant part. Plant parts designated by a and b are samples from different plants.

Crop and field	Plant part	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg
2014 samples							
Corn C1	Grain	51.1	1,152	0.52	18.3	3,502	0.74
Corn C1	Grain, duplicate	50.7	1,169	0.53	91.0	3,526	0.66
Corn C1	Non-grain	1,905	1,769	44.9	417	15,046	91.2
Corn C1	Non-grain, dup.	2,013	1,833	47.5	526	15,385	91.2
Corn C1	Root	2,442	1,461	55.5	693	5,553	530
Corn C1	Root, duplicate	3,085	1,751	67.1	876	6,586	689
Corn C2	Grain, a	42.3	922	0.33	20.5	2,708	0.47
Corn C2	Non-grain, a	5,597	3,271	62.7	438	15,649	93.8
Corn C2	Root, a	1,772	1,831	45.4	1,818	8,492	478
Corn C2	Grain, b	44.6	946	0.29	16.2	3,088	1.36
Corn C2	Non-grain, b	2,918	1,353	22.6	215	13,298	29.9
Corn C2	Root, b	2,828	1,303	35.9	861	12,955	359
Soybean S1	Grain	2,406	2,547	47.6	107	20,956	2.42
Soybean S1	Non-grain	22,018	8,565	502	303	17,428	129
Soybean S1	Root	2,378	1,183	81.0	1,340	2,278	1,008
Soybean S2	Grain, a	2,872	2,827	56.2	123	19,596	3.04
Soybean S2	Non-grain, a	15,817	7,002	413	1,465	20,865	191
Soybean S2	Root, a	947	977	44.0	5,229	3,383	638
Soybean S2	Grain, b	2,562	2,778	50.4	125	19,296	2.04
Soybean S2	Non-grain, b	19,059	7,236	452	970	22,833	256
Soybean S2	Root, b	1,828	1,109	66.0	3,362	5,222	550
Sorghum M1	Grain, a	142	1,640	1.81	50.0	3,943	1.43
Sorghum M1	Non-grain, a	5,591	3,106	91.9	87.5	24,076	64.0
Sorghum M1	Root, a	1,516	670	25.1	936	8,542	145
Sorghum M1	Grain, b	154	1,147	2.17	33.9	3,377	0.75
Sorghum M1	Non-grain, b	7,701	3,837	136	109	28,176	67.9
Sorghum M1	Root, b	1,832	912	34.8	759	8,467	417
Alfalfa A1	Plant	10,173	3,683	263	1,769	31,809	192
Alfalfa A1	Root	6,165	3,051	187	4,964	5,851	833
2015 samples							
Corn C3	Grain	37.8	1,206	0.31	54.4	2,890	<10
Corn C3	Non-grain	3,135	3,545	58.8	405	7,831	81
Corn C3	Roots	1,577	1,656	36.6	1,664	9,041	412
Corn C4	Grain	28.5	1,023	0.36	31.8	2,730	<10
Corn C4	Non-grain	2,576	2,460	54.2	696	20,358	193
Corn C4	Roots	3,783	2,699	83.1	2,702	11,362	1,451
Corn C5	Grain	32.7	1,051	0.41	38.9	3,015	<10
Corn C5	Non-grain	2,636	3,114	53.9	712	23,500	18
Corn C5	Roots	4,667	2,800	84.2	1,702	6,995	405
Soybean S3	Grain	2,603	2,781	48.8	227	17,662	<10
Soybean S3	Non-grain	17,474	8,314	413	1,469	14,750	117
Soybean S3	Roots	3,986	1,555	122	4,746	4,056	1049
Sorghum M2	Grain	304	1,743	4.54	73.0	3,428	<10
Sorghum M2	Non-grain	4,127	1,929	70.4	185	24,250	41
Sorghum M2	Roots	2,695	1,723	50.0	1,098	12,840	575
Alfalfa A2	Plant	19,217	3,612	330	2,160	27,196	88
Alfalfa A2	Roots	7,559	2,410	144	1,455	10,795	603

Table 12. Range and mean of constituent concentrations in nitric acid digest of corn plant samples. Concentration is for dry weight of soil.

	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg
Grain						
Range 2014	42.3-51.1	922-1,170	0.29-0.53	16.2-91.0	2,710-3,530	0.47-1.36
Mean 2014	47.2	1,050	0.42	36.5	3,210	0.81
Range 2015	28.5-37.8	1,020-1,210	0.31-0.41	31.8-54.4	2,730-3,010	<10
Mean 2015	33.0	1,090	0.36	41.7	2,878.1	-
Mean 2014, 2015	40.1	1,070	0.39	39.1	3,044	-
Non-grain						
Range 2014	1,910-5,600	1,350-3,270	22.6-62.7	215-526	13,300-15,600	29.9-93.8
Mean 2014	3,108	2,057	44.39	399	14,845	76.5
Range 2015	2,580-3,140	2,460-3,540	53.9-58.8	405-712	7,830-23,500	18-193
Mean 2015	2,782	3,040	55.65	604	17,230	97.3
Mean 2014, 2015	2,945	2,548	50.02	502	16,037	86.9
Roots						
Range 2014	1,770-3,090	1,300-1,830	35.9-67.1	693-1,820	5,550-13,000	359-689
Mean 2014	2,532	1,587	50.98	1,062	8,396	514
Range 2015	1,580-4,670	1,660-2,800	36.6-84.2	1,660-2,700	6,990-11,400	405-1,451
Mean 2015	3,342	2,385	67.96	2,023	9,133	756
Mean 2014, 2015	2,937	1,986	59.47	1,542	8,764	635

Table 13. Range and mean of constituent concentrations in nitric acid digest of soybean plant samples. Concentration is for dry weight of soil.

	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg
Grain						
Range 2014	2,410-2,870	2,550-2,830	47.6-56.2	107-125	19,300-21,000	2.04-3.04
Mean 2014	2,613	2,717	51.41	118.44	19,950	2.50
Value 2015	2,603	2,781	48.8	227	17,662	<10
Mean 2014, 2015	2,608	2,749	50.1	173	18,806	-
Non-grain						
Range 2014	15,800-22,000	7,000-8,560	413-502	303-1,460	17,400-22,800	129-256
Mean 2014	18,965	7,601	455.70	913	20,375	192
Value 2015	17,474	8,314	413	1,469	14,750	117
Mean 2014, 2015	18,219	7,958	434	1,191	17,563	154
Roots						
Range 2014	947-2,380	977-1,180	44.0-81.0	1,340-5,230	2,280-5,220	550-1,010
Mean 2014	1,718	1,090	63.69	3,310	3,628	732
Value 2015	3,986	1,555	122	4,746	4,056	1049
Mean 2014, 2015	2,852	1,323	92.8	4,028	3,842	890

Table 14. Range and mean of constituent concentrations in nitric acid digest of sorghum plant samples. Concentration is for dry weight of soil.

	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg
Grain						
Range 2014	142-154	1,150-1,640	1.81-2.17	33.9-50.0	3,380-3,940	0.75-1.43
Mean 2014	148	1,393	1.99	41.94	3,660	1.09
Value 2015	304	1,743	4.54	73.0	3,428	<10
Mean 2014, 2015	226	1,568	3.26	57.5	3,544	-
Non-grain						
Range 2014	5,590-7,700	3,110-3,840	91.9-136	87.5-109	24,100-28,200	64.0-67.9
Mean 2014	6,646	3,472	113.83	98.02	26,126	65.9
Value 2015	4,127	1,929	70.4	185	24,250	41
Mean 2014, 2015	5,387	2,700	92.1	142	25,188	53.4
Roots						
Range 2014	1,520-1,830	670-912	25.1-34.8	759-936	8,470-8,540	145-417
Mean 2014	1,674	791	29.94	848	8,504	281
Value 2015	2,695	1,723	50.0	1,098	12,840	575
Mean 2014, 2015	2,184	1,257	40.0	973	10,672	428

Table 15. Range and mean of constituent concentrations in nitric acid digest of alfalfa plant samples. Concentration is for dry weight of soil.

	Ca, mg/kg	Mg, mg/kg	Sr, mg/kg	Na, mg/kg	K, mg/kg	U, µg/kg
Above ground plant						
Value 2014	10,200	3,683	263	1,769	31,809	192
Value 2015	19,217	3,612	330	2,160	27,196	88
Mean 2014, 2015	14,709	3,648	297	1,965	29,502	140
Roots						
Value 2014	6,160	3,050	187	4,960	5,850	833
Value 2015	7,559	2,410	144	1,455	10,795	603
Mean 2014, 2015	6,859	2,730	165	3,208	8,322	718

Discussion

Figure 3 displays the uranium content (in µg/km) in the plant parts of crops in the study area versus the uranium concentration (in µg/L) in the groundwater used to irrigate the crops. The values of uranium concentration in the grain of corn, soybean, and sorghum are less than those in the groundwater used to irrigate the crops (the points on the graph lie below the line for plant concentration equals water concentration when expressed in the manner in the graph; a L of fresh to slightly saline water is closely equivalent to a kg of water. This is in contrast to the generally higher uranium values in the above ground non-grain plant material of these crops and alfalfa than in the irrigation well water (the points lie above the line, although a value for corn is near the line). The uranium values for the roots lie substantially above the line, representing the much higher concentration in the roots than in the irrigation water.

Both the above ground non-grain plant material and the roots of all the crops sampled in this study contain uranium contents greater than those in the water extracts of the sampled soils (Figure 4). The grain of the corn, soybean, and sorghum plants sampled have uranium concentrations less than the soil water. In comparison, essentially all of the sampled plant parts contain lower uranium concentrations than in the dilute acid extracts of the soils (Figure 5); the roots of one corn sample had a uranium content approximately equal to that in the acid extract of the soil sampled a depth of 3-4 ft. These data suggest that the non-grain plant parts and the roots extract uranium available in the soil in concentrations between those in the deionized water extracts and the dilute nitric acid extracts of the upper 4 ft of soil.

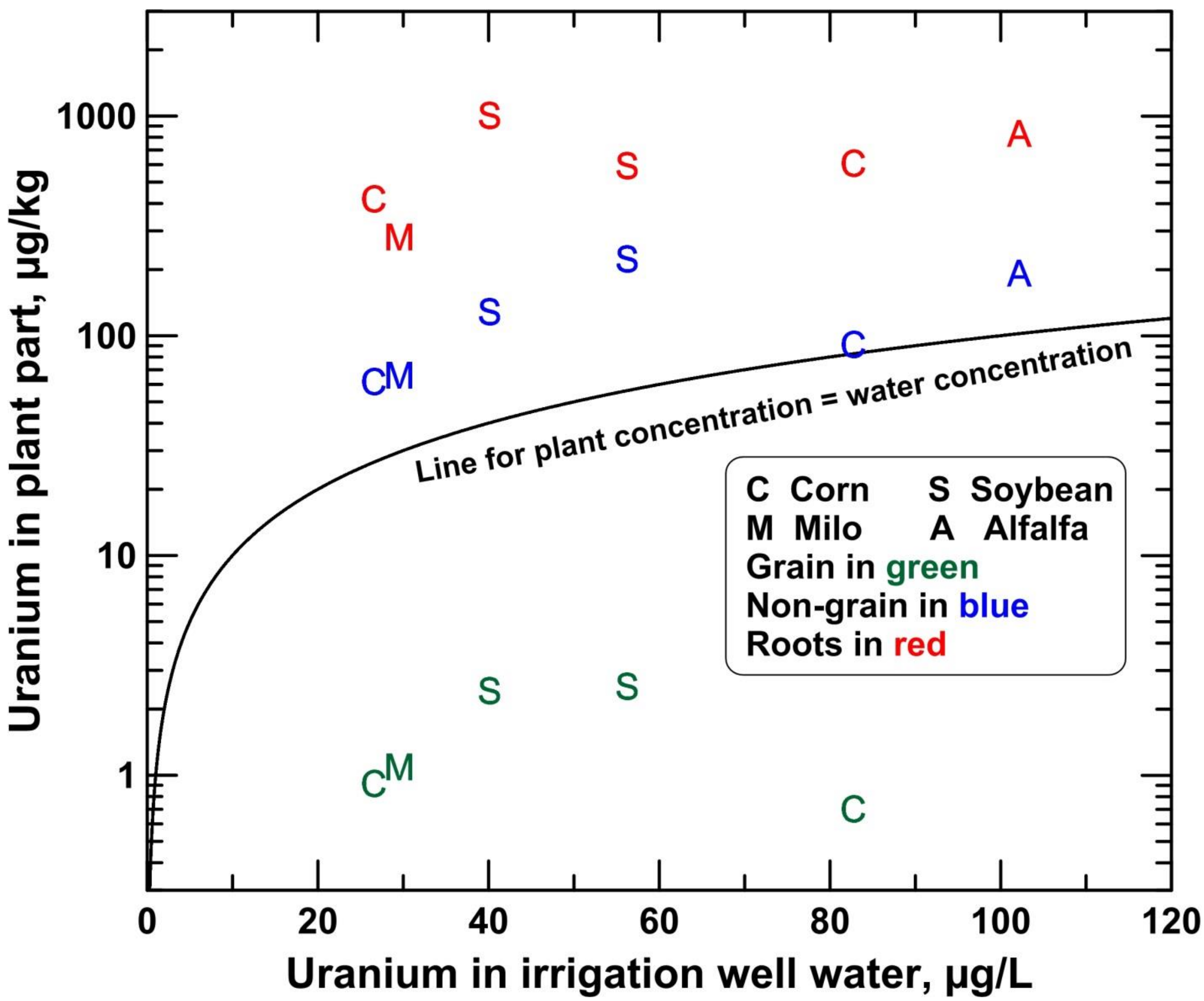

Figure 3. Uranium concentration in the plant parts of corn, soybean, sorghum (milo), and alfalfa versus uranium concentration in groundwater from irrigation wells associated with the crop fields from which the plants were sampled. The values plotted are for the 2014 samples.

Figure 6 shows the mole ratio of uranium content divided by the sum of major and minor metals (potassium, calcium, magnesium, sodium, and strontium) concentrations in the plant parts of corn, soybean, sorghum (milo), and alfalfa versus the mole ratio for uranium concentration divided by the sum of these same metals (cations) in groundwater from irrigation wells associated with the crop fields from which the plants were sampled. The plot illustrates the degree of concentration of uranium to total metals (cations) in the two media; the line on the graph represents plant ratios that are equal to water ratios. The graph shows that the uranium in the grain and the above ground non-grain plant material is much lower relative to the metals in the plant parts than in the water. Most of the roots have lower uranium to metals ratios than in the water, although much closer to the equal ratio line than for the grain and above ground non-grain material; the roots of soybean plants from one field had ratios higher than in the water. In general, this graph illustrates that the uranium being used for irrigation, which increases the uranium concentration in the soil water extracted by the plants, is primarily concentrated in the roots relative to the cations also extracted from the soil. Less uranium is drawn into the above ground non-grain plant material relative to the cations, and much, much less uranium is incorporated in the grain relative to the cations than present in the irrigation water.

The mole ratio of uranium concentration divided by the sum of major and minor cation concentrations in the water extracts of soils is plotted versus the same mole ratio for the plant parts of corn, soybean, sorghum (milo), and alfalfa grown in the fields from which the soils were sampled in Figure 7. Uranium is drawn into the grain and nearly all of the above ground non-grain plant parts from the soil at a lower concentration relative to the total cation concentration in the water extract of the soils. The uptake of uranium, available in the water extracts of soils, by the roots is at a higher content relative to the cation sum in the water extracts.

Figure 8 is a similar graph to that in Figure 7 except that it represents the mole ratio of uranium to the cation sum in the dilute acid extracts of the soils versus that ratio for plant parts. Uranium is drawn into the grain and all of the above ground non-grain plant parts from the soil at substantially lower concentrations relative to the total cation concentration in the dilute nitric extracts of the soils. The uptake of uranium, available in the acid extracts of soils, by the roots ranges from above to below the uptake of total cations available in forms that can be released in the dilute acid extracts (points plot above and below the soil ratio equals plant ratio line in Figure 8).

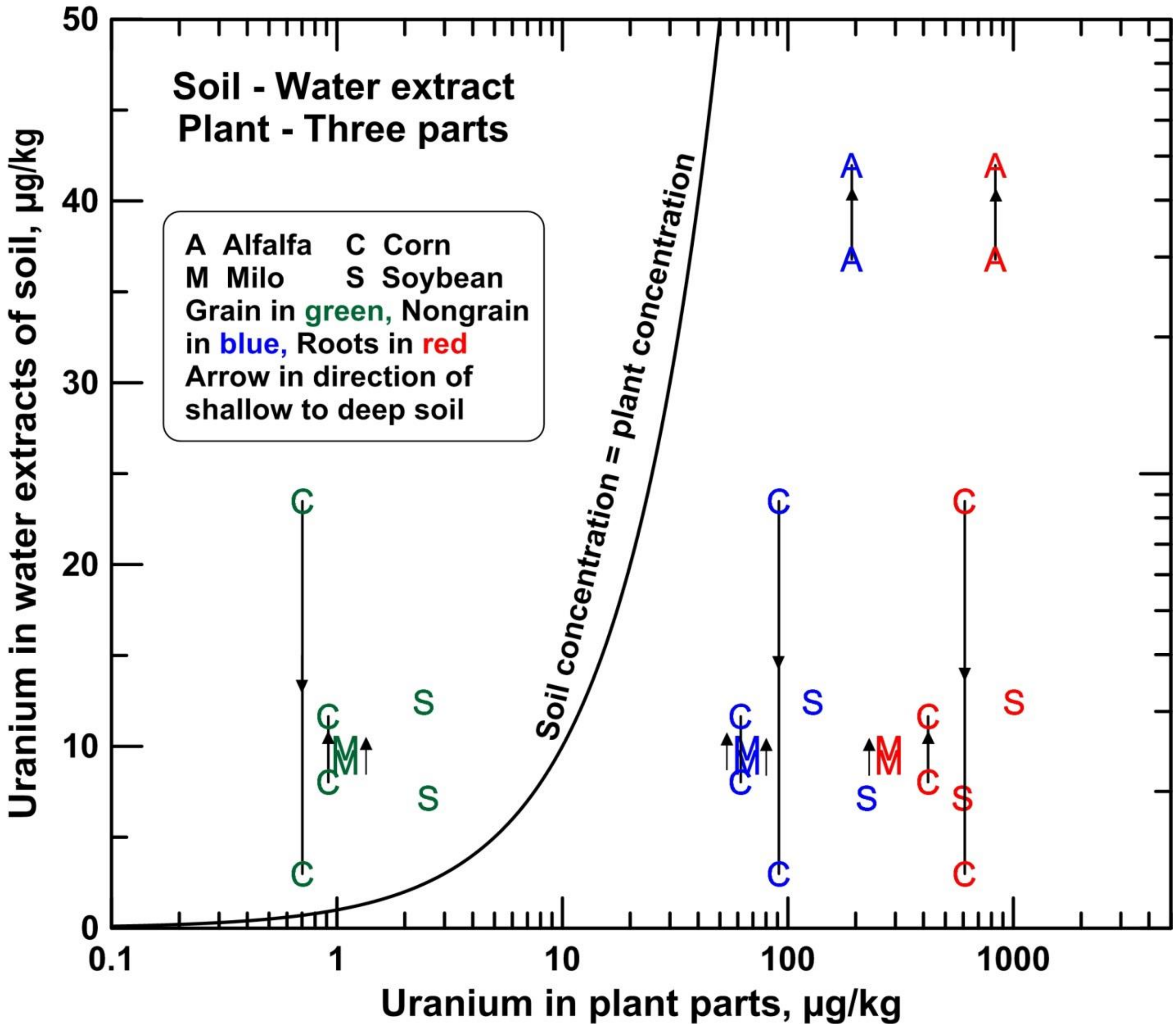

Figure 4. Uranium concentration in the water extract of soils versus uranium content of plant parts of corn, soybean, sorghum (milo), and alfalfa grown in the fields from which the soils were sampled. The values plotted are for the 2014 samples.

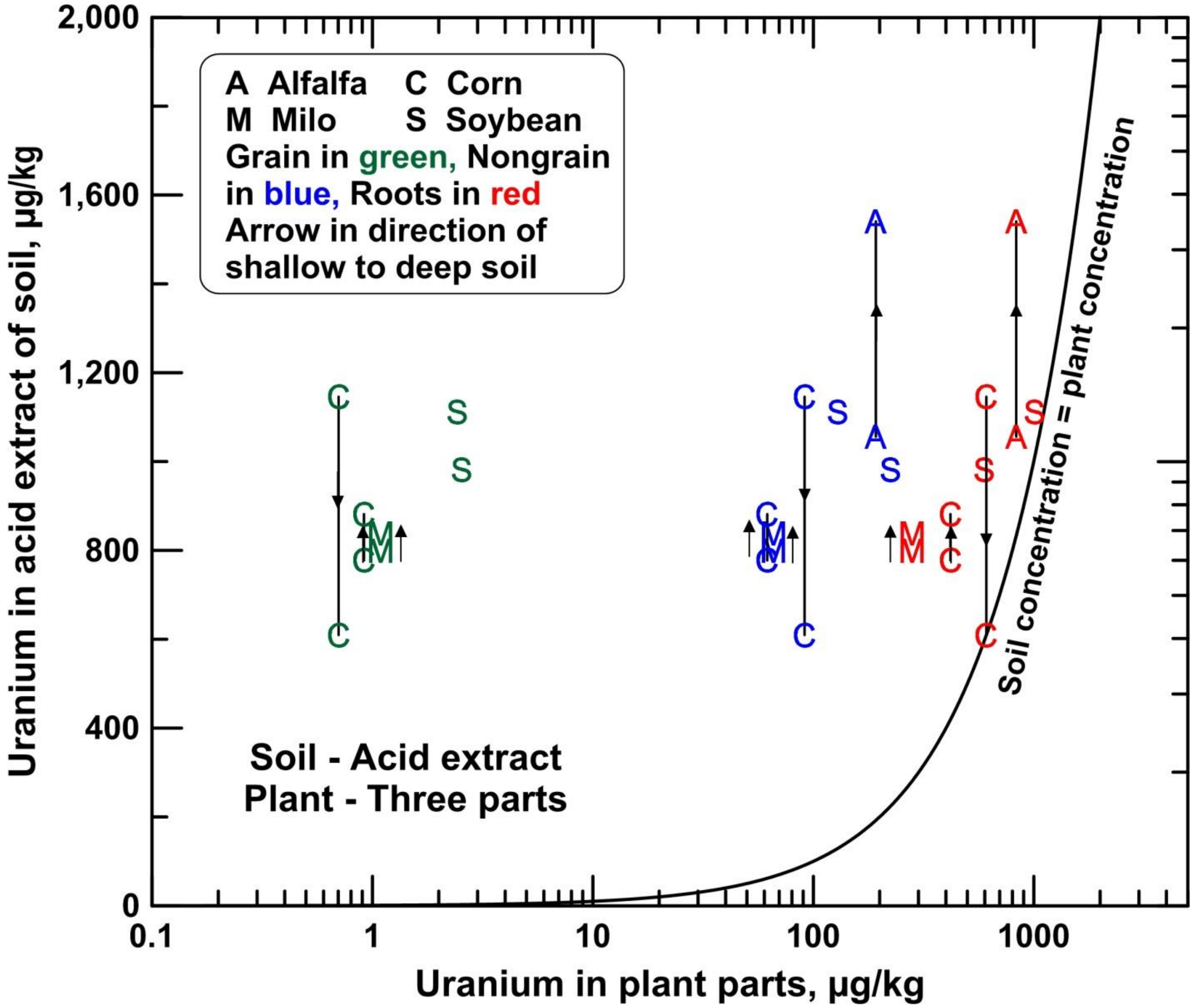

Figure 5. Uranium concentration in the dilute nitric acid extracts of soils versus uranium content of plant parts of corn, soybean, sorghum (milo), and alfalfa grown in the fields from which the soils were sampled. The values plotted are for the 2014 samples.

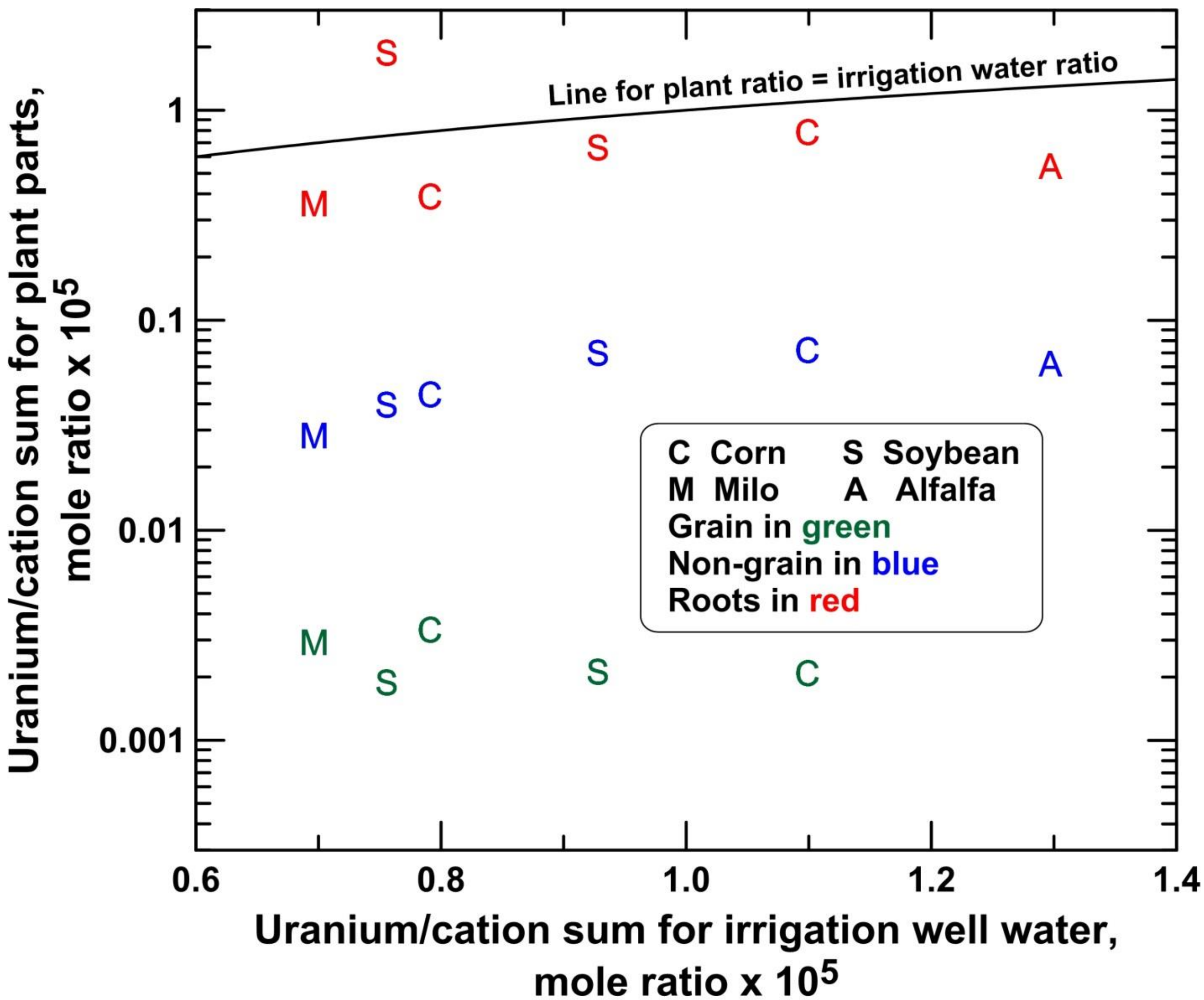

Figure 6. Mole ratio of uranium concentration divided by the sum of major and minor metals concentrations in the plant parts of corn, soybean, sorghum (milo), and alfalfa versus the same mole ratio for groundwater from irrigation wells associated with the crop fields from which the plants were sampled. The values plotted are for the 2014 samples.

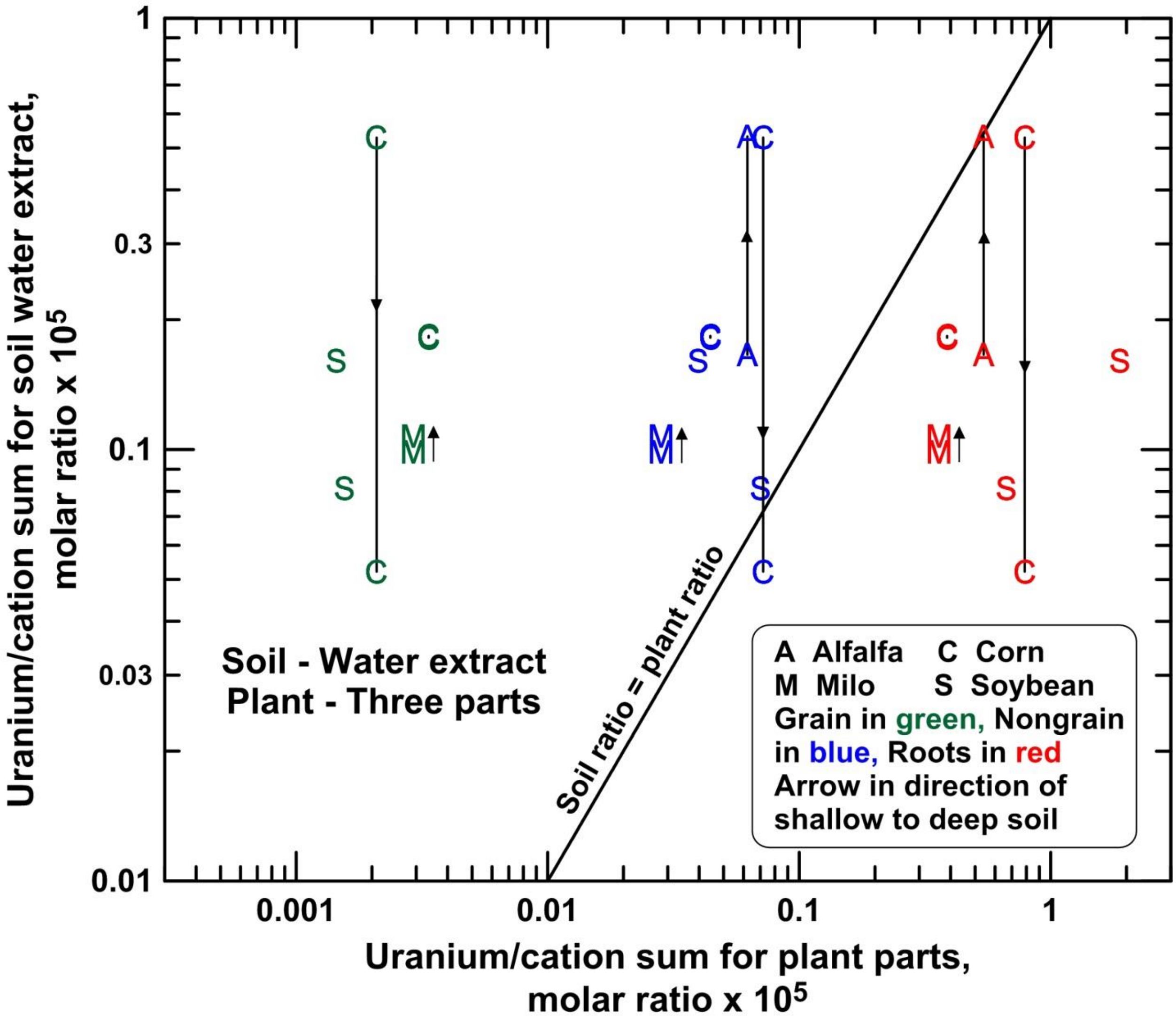

Figure 7. Mole ratio of uranium concentration divided by the sum of major and minor cation concentrations in the water extracts of soils versus the same mole ratio for the plant parts of corn, soybean, sorghum (milo), and alfalfa grown in the fields from which the soils were sampled. The values plotted are for the 2014 samples.

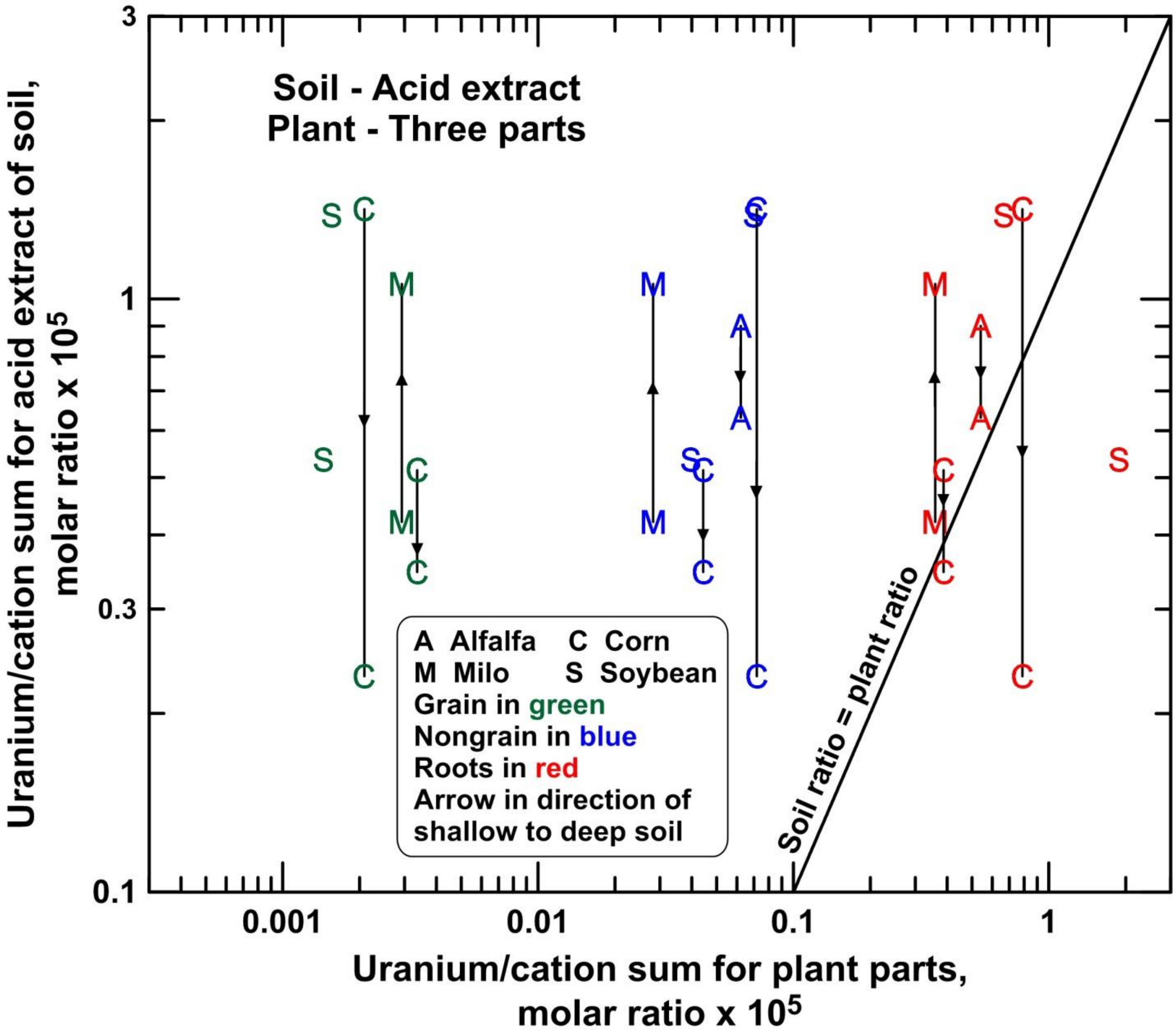

Figure 8. Mole ratio of uranium concentration divided by the sum of major and minor cation concentrations in dilute nitric acid extracts of soils versus the same mole ratio for the plant parts of corn, soybean, sorghum (milo), and alfalfa grown in the fields from which the soils were sampled. The values plotted are for the 2014 samples.

Conclusions

Uranium concentrations range widely in the Arkansas River, the source of the high uranium input to the Arkansas River valley in southwestern Kansas. Although low to moderate flows contain uranium concentration exceeding the MCL for public supplies of drinking water, high flows have concentrations below the MCL. However, the high flows bring larger loads of uranium into the valley. These loads become distributed across the area in the soils and the groundwater of the High Plains aquifer where river water seeps below the channel, where river water is diverted for irrigation, and where groundwater contaminated by river water flows down gradient. The uranium concentration in soils irrigated by the river water and by groundwater contaminated by river water increases in the soil and the irrigation return flow as evapotranspiration consumes water and leaves behind the residual uranium in a smaller volume of water. The continued pumping of groundwater and infiltration of return flow is expected to cause a long-term increase in the uranium content of the groundwater in the river corridor.

The uranium content of the soils in the river valley has increased where the river or groundwater used for irrigation has a higher uranium content than the background. The uranium content of the dilute acid extract of soils is much higher than in the water extract of the soils. The crops (corn, soybean, sorghum, alfalfa) grown on the soils irrigated with higher uranium than background draw up uranium into the different parts of the plant. Most of the uranium uptake remains in the roots, with a smaller amount entering the above ground non-grain plant material, and an even smaller amount taken up into the grain. The uranium uptake by the roots is at amounts greater than the uptake of total cations when concentrations in the deionized water extracts of soils are considered. However, the relative uptake of uranium to uptake of cations is generally in the same range when concentrations available in the dilute nitric acid extracts of soils are considered. The uptake of uranium relative to cations in the above ground non-grain plant material is at a lower ratio than in both the water and dilute acid extracts of the soils. The uptake of uranium by the grain of corn, soybean, and sorghum is at a much lower rate relative to cation uptake from the plant available amounts in the water and dilute acid extracts of soils.

The finding of the low uranium content in the grain and the general greater concentration of uranium in the roots relative to both the grain and the non-grain plant parts is very important information for agriculture in the study area. This means that the uranium loads are not preferentially being taken up into the plant materials used for animal feed and human food. This relieves a substantial prior concern of the impact of high uranium in the area on agricultural crops. Although the levels of uranium in the grain of crops are very low, the content of some of the above ground non-grain plant material that is used for animal feed, such as alfalfa, could be at levels that should be examined relative to animals if this plant matter provides the main portion of animal food. However, it is difficult to determine this because there are no current guidelines on the maximum amount of uranium in feed that is tolerable by animals (Lattermoser, 2011; National Research Council, 2005).

Future Work

The analysis of uranium in the soil samples collected in the fall of 2015 is currently being completed; the results will be used to compare the 2014 and 2015 sample data for uranium concentrations and the uptake of uranium relative to cations in plant parts compared to the ratios in the soil extracts. A paper will be prepared for publication in a peer-reviewed journal that reports the results, conclusions, and implications, including comparison to studies of uranium in the soils and plants of areas of uranium mines (spoils and remediated land). The results and interpretation will be used to determine the type of data most needed for future research to assess what is the long-term (over decades) fate, transport, and impact of high-uranium river water in southwest Kansas, as well as other areas similarly impacted in the U.S., which will be proposed to other funding programs and agencies. The investigation of the long-term effect is needed because the high loads of uranium in the Arkansas River continue to enter the river valley in southwest Kansas and remain there because no river flow currently exits the area (the river channel is essentially always dry downstream of Garden City and has been so since the latter part of 2001.

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Water Research for the Fort Riley Net Zero Initiative

Basic Information

Title:	Water Research for the Fort Riley Net Zero Initiative
Project Number:	2014KS180S
USGS Grant Number:	
Sponsoring Agency:	EPA
Start Date:	11/25/2015
End Date:	7/31/2016
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Quantity, None
Descriptors:	None
Principal Investigators:	Stacy Lewis Hutchinson, Gerad Middendorf, Natalie Mladenov

Publication

1. Hutchinson, Stacy L, 2016. Final Report. Disinfection of biological agents in the field using a mobile advanced oxidation process. Kansas State University, Manhattan, Kansas.

Summary of work to date:

Kansas State University is working with Fort Riley personnel, EPA ORD, and EPA Region 7 to develop strategies for meeting the Department of Defense Net Zero Water goals. Specific project objectives for the Fort Riley demonstrations are:

1. Investigation of methods for safe reuse of waste water through the decentralized treatment of water from sewer lines (Titled: Decentralized Waste Water Treatment Technology Demonstration);
2. Containment, control and disposal of large volumes of wastewater following an event involving biological agents (Titled: Wastewater Security Investigation);
3. Use of engagement, education, motivation, and empowerment to reduce water demand at Ft. Riley, with a measurement of the effectiveness of each (Titled: Demand Side Outreach and Intervention Study).

Research was initiated in January 2014 and work is ongoing for the wastewater reuse and water security project. The Demand Side Outreach and Intervention Study was completed in December 2014 and the water security project final report was submitted in January 2016 (see attached).

Specific Project work:

1. Decentralized Waste Water Treatment Technology Demonstration – supporting one MS student on this project. Continued to participate in monthly project meetings via telephone and attended several on-site meetings with EPA, Fort Riley, and contractors to discuss system function, operation and monitoring. Continued issues with the MBR function have resulted in the collection of very little viable resear.

2. Wastewater Security Investigation – Supporting one MS student on this project. Continued to assess AOP trailer function and determine the impact of total suspended solids on the performance of the system. While there is solid performance of the system about 50% of the time, problems with the UV light source continue to plague tests and require maintenance. Additional maintenance was performed and more test to determine what was causing the inconsistency of performance. Residual chloramines were determined to impact system performance and studies are being re-worked to dechlorinate and/or use natural waters for testing.

3. Demand Side Outreach and Intervention – no work this year.

Final Report

Disinfection of biological agents in the field using a mobile advanced oxidation process

by

Kansas State University
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for

U.S. Environmental Protection Agency
Office of Research and Development
National Homeland Security Research Center
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Interagency Agreement Number DW-14-92385901-0

Final Report
January 2016

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Acronyms and Abbreviations

AOP	advanced oxidation process
EPA	Environmental Protection Agency
H_2O_2	hydrogen peroxide
HO_2^-	hydroperoxide ion
MP	medium pressure
mg/L	milligrams per liter
mL	milliliters
O_2	oxygen
O_3	ozone
$\bullet OH$	hydroxyl radical
	Development
ORD	Office of Research and
PI	Principal Investigator
QA	Quality assurance
QAM	Quality Assurance Manager
QAPP	Quality Assurance Project Plan
QC	Quality control
scfh	standard cubic feet per hour
SOP	standard operating procedures
SS	stainless steel
TiO_2	titanium dioxide
UV	ultraviolet
WAM	Work Assignment Manager

PROJECT OBJECTIVES

Project Objective

The Army's Net Zero initiative seeks to reduce water consumption and improve reuse on military installations throughout, both locally and globally. In response to the necessity of water security to protect against contamination, promote control, and the handling of large volumes of wastewater following an event involving biological agents the following research to optimize a mobile Advanced Oxidation Process was developed. The research seeks to evaluate the limitations, applicability, and advantages of such a process and how well it performs under varying water quality conditions.

The use of a mobile system is key for situations in theatre where local treatment and fresh water is not readily available. Such water could be hazardous due to elevated levels of TSS, nutrients, harmful microorganisms, or chemical contamination. In dire situations water reuse may be necessary and precautions must be exercised to ensure contamination does not occur from wash water that might be recycled. In the field immediate access to chemicals such as chlorine may not be available and while effective, the transport of such chemicals could prove hazardous in the event of an attack. The design of the AOP eliminates the need for additive chemicals, concerns for residual chemicals, undesired reactions with the chemical and possible contaminants, and is transportable from one station to the next.

Convoys are vulnerable targets in desert regions with extensive open space and routinely followed trails making for easy targets. These convoys carry vital supplies including sustenance, medical equipment, and fresh water between operations. When convoys are not available or become delayed soldiers must rely on local sources for provisions. Advanced filtration, chemical treatment options, and fresh sources are frequently scarce. Soldiers who have access to a local system or well water may be fortunate, but the water cannot be guaranteed for safe consumption or secondary utilization without additional treatment.

The Army and ORD are currently partnering to promote and demonstrate innovative technologies on Army installations in support of the Army's Net Zero initiative. Through ORD's research program, EPA scientists and engineers are working with the Army and other partners to identify specific installation technology needs. One challenge of interest is containment, control and disposal of large volumes of wastewater following an event involving biological or agents. Wash racks, or areas where military vehicles are washed after exercise, provide researchers access to water contaminated with oil, grease, some metals and mixtures of suspended solids (dirt and mud). Access to the wash rack water provides a unique opportunity to evaluate disinfection of biological agents in the field with water that could hinder the disinfection process.

The proposed AOP consists of ozone and ultraviolet radiation in combination to produce three treatment measures including direct and indirect ozonation and UV irradiation. Produced ozone is injected into the water stream, which is then exposed to UV radiation to induce the formation of H_2O_2 and indirect oxidation. The limitations of an AOP are not fully understood while limitations of the individual processes have been examined in previous studies. The combined effects of UV and Ozone together potentially overcome these limitations by advancing the rate of oxidation and speeding inactivation of microorganisms.

The potential of this process as designed has not been extensively studied in the combination proposed nor with respect to contact time and water quality interference. This investigation has been designed to evaluate the operation of the AOP system as it performs relative to elevated TSS and flowrates for optimal performance as designed. All components are designed within parameters suggested by existing literature including the intensity of the medium pressure UV lamp at 254 nm and the high concentration of ozone at 5.8 mg/L.

This project will examine the inactivation and/or removal of biological agents in wash water using portable unit treatment processes. Wash water will come from the wash racks at Ft. Riley. The water in these basins is representative of water washed from cars or structures after an outdoor contamination event so it is uniquely suited for use as a "real world" surrogate. Biological agents will be spiked into streams of clean tap water and dirty water. The effect of dirt and grime on biological agent removal efficiency will be determined and compared with results from clean tap water.

The objectives of this investigation aim to evaluate the limitations of an Advanced Oxidation Process treatment with set values of UV irradiation and Ozone concentration, and optimize the performance of the system according to those limitations. Experimentation was proposed to analyze the influence of total suspended solids and flowrate on the ability of the system to inactivate high levels of inoculum in the form of Escherichia coli. Based on the proposed source water from military field vehicle wash operations other possible parameters that might cause differences of inactivation include temperature, bio-solids, nutrient load, and pH.

Methods & Procedures

AOP System Design

The AOP trailer system consists of a 1-inch stainless steel (SS) pipe loop system, a variable speed recirculation pump, a MP UV lamp and a LP UV lamp, an oxygen (O_2) concentrator, an O_3 generator, an ozone injection system, and an O_3 destructor (Figure 2-1). Influent samples were removed from the blend tank used to feed the AOP unit, and just after initial entrance to the unit to establish fluctuations during loading. Effluent samples were removed from the sampling port immediately before the treated water was discharged. Water with biological agents was exposed to the ozone and UV light as it passed through the AOP unit.

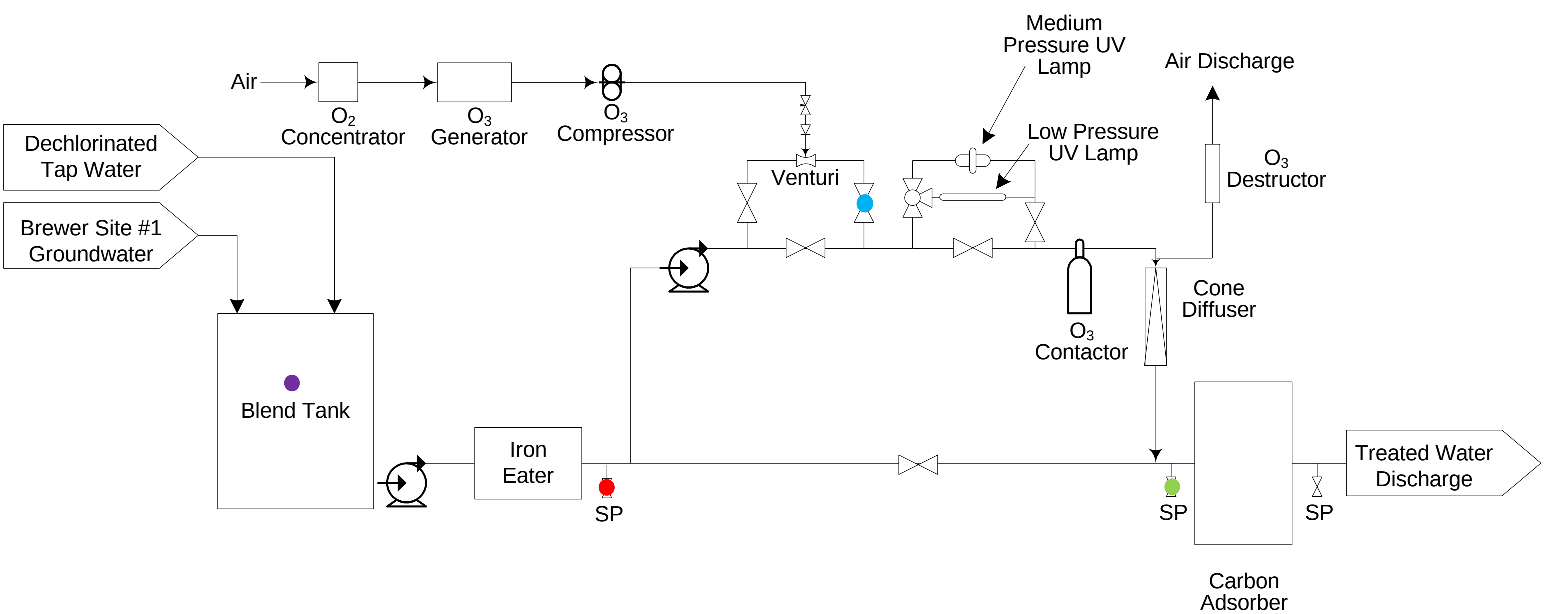


Figure 2-1 Schematic Diagram of Pilot-Scale AOP System

● Supply tank sample port ● Cart influent sample port ● Ozone sample port ● Effluent sample port

UV radiation was provided by a medium pressure (MP) UV reactor (Aquionics InLine 20 UV System, Aquionics, Inc., Erlanger, KY) in Figure 2-2. O_3 was generated using an O_2 concentrator and an O_3 generator. The O_2 concentrator separates O_2 from compressed air through a pressure swing adsorption (PSA) process. The PSA process uses a molecular sieve (a synthetic zeolite), which adsorbs nitrogen and other impurities from the air at high pressure and desorbs them at low pressure. The O_2 concentrator is designed for a maximum airflow rate of 6.6 standard cubic feet per hour (scfh). The O_2 is then fed into the O_3 generator. In the reaction chamber of the O_3 generator, the feed gas is exposed to multiple high-voltage electrical discharges, producing O_3. The O_3 is injected into the system through a venturi-type, differential pressure injector (Mazzei ¾-inch MNPT Model 684) located on the discharge side of the system recirculation pump (¾-horsepower G&L Pump NPE/NPE-F). When the contaminated water enters the injector inlet, it is constricted towards the injection chamber and emerges as a high-velocity jet stream. The increase in velocity through the injection chamber results in a decrease in pressure, thereby enabling O_3 to be drawn through the suction port and entrained into the motive stream. The venturi is assisted by an ozone compressor (Air Dimensions, Inc. DiaVac pump) to allow the system to operate at lower differential pressures while maintaining a high ozone concentration in the system. The ozone concentrations are further increased by the use of an ozone cone diffuser shown in Figure 2-3. Excess O_3 is converted back to O_2 using an O_3 destruct unit before it is vented into the atmosphere. The recirculation pump is connected to a variable-speed controller (1AB2 AquaBoost II Controller), which enables the flow rate in the loop to be set to any desired value.

Treatment Process

The AOP disinfection technology is UV irradiation combined with O_3. Due to the high molar extinction coefficient of ozone, UV radiation can be applied to ozonated water to form highly reactive •OH. Because photolysis of O_3 generates H_2O_2, the UV/O_3 process involves the disinfection mechanisms present in O_3/H_2O_2 and UV/H_2O_2 AOPs. For instance, H_2O_2 in conjunction with O_3 can enhance the formation of •OH. H_2O_2 is a weak acid that partially dissociates into hydro-peroxide ion (HO_2^-) in water. The HO_2^- ion can rapidly react with O_3 to form •OH. Meanwhile, hydroxyl radicals are produced from the photolytic dissociation of H_2O_2 in water by UV radiation. Disinfection can occur either by direct photolysis or by reactions with •OH.

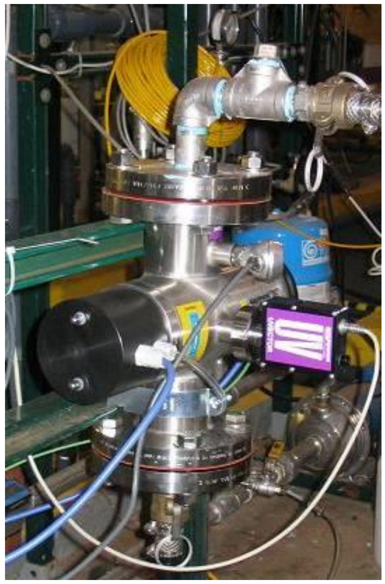


Figure 2-2. Medium-Pressure UV Lamp System

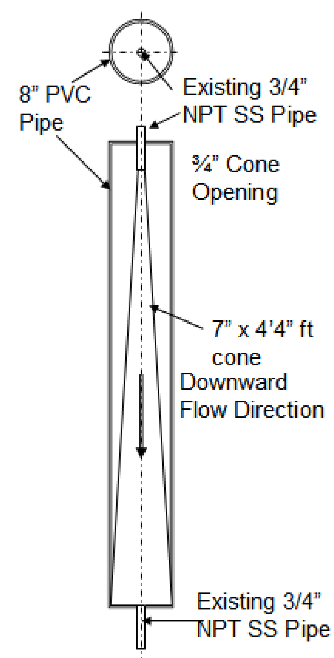


Figure 2-3. Cone Diffuser for Ozone Concentration

Experimental Design

The investigation consisted of the treatment of *Escherichia coli* in clean tap water, dirty water from Fort Riley wash racks, and naturally sourced water from a local runoff collection pond using the mobile AOP trailer.

All tests were conducted on the Kansas State University campus in the Biological and Agricultural Engineering workshop. Water from the wash racks was used directly without dilution to establish whether an interference of turbidity existed. Carboys of water from the wash racks at Ft. Riley were collected as needed along with water from a local runoff pond. Additional treatment analysis consisted of the influence of flowrate, bacteria interaction with suspended particles, and water quality.

The MP-UV lamp installed in the AOP system provided UV radiation at an emission spectrum between 200 nm and 300 nm with a power requirement of 0.9 kW and a UV dose >10 mg/cm^2. The UV unit had one setting, so UV conditions were constant for all experiments in the study. Preliminary tests were performed by running carbon-filtered tap water and ozone through the AOP system to test the capacity of the ozone generator and to determine the ozone concentration in the AOP system. The setting of the ozone generator was adjusted during the preliminary tests to achieve the target ozone concentration of approximately 5.8 mg/L or greater in the AOP system. The levels of ozone were never definitively established due to the high reactivity of O3. Settings for the ozone generator were left at the highest values possible, but could not be recorded conclusively. The presence of ozone was observed throughout testing, but a true value of concentration was never determined. Unable to establish; consistent presence confirmed.

Experiments were conducted by filling the feed tank with *E. coli* at an initial microbial density of $1x10^6$ cfu/ml or mpn/ml. Water was fed to the AOP unit at two different rates, 6 gpm or <4gpm. One sample was removed from the feed tank to determine the initial concentration (T_i). Water exiting the AOP unit (effluent samples) were sampled at the last sampling point before the water left the AOP unit (C_e). Samples were removed at 1, 5, 10, 15, and 20 minutes after the contaminated water feed to the AOP unit started. Disinfection was assessed by examining the log reduction (LR) of samples taken at 1, 5, 10, 15, and 20 minutes compared to the initial microbial density in the feed tank using the following equation:

$$LR = -log\frac{C_e}{T_i}$$

Table 2-1a lists the primary experimental design parameters for AOP disinfection of *E. coli*. Table 2-1b shows a summary of the test runs for the experimental program. Clean tap water was pumped through the AOP trailer for 20 minutes prior to each experiment to clear the disinfection unit of particulates and residual bacteria. During this same time bacteria inoculum was allowed to circulate in the mixing tank for consistent distribution.

Table 2-1. Experimental Design Parameters

Parameters	Designed Values
Source Water	Pond/Lagoon water, Dechlorinated tap water
dilution water	Pond/Lagoon water, Dechlorinated tap water
target contamination	*Escherichia coli*
Concentration of contaminant	10^3-10^5 mpn/mL
AOP method	UV irradiation/O3
Type of UV lamp	Medium-pressure UV lamp
UV Intensity	preset level kept constant
Ozone concentration	approx. 5.8 mg/L (indeterminate)
Temperature Range	20-23°C
Flow rates	less than 4 gpm and 6 gpm
Recirculation ratio	once-through flow
Collection Points	T, C0, C5, C10, C15, C20, E5, E10, E15, E20
Test Duration	20 minutes

Evaluation objectives

Measurement analyte, location, reporting units, and sampling frequency for critical measurements are summarized in Table 2-2. Table 2-3 summarized the measurement analyte, reporting units, sampling type, sample location, and frequencies for non-critical measurements.

Table 2-2. Critical Parameter Measurement Summary

Measurement	Reporting Unit [a]	Sampling Location	Measurement Purpose
E. coli	mpn/ml	Supply tank, and Influent to Cart and Effluent from Outlet of AOP System at 0, 1, 5, 10, 15, and 20 minutes after the start of a test run.	Primary microbial contaminant for study
Ozone	mg/L	Outlet sampling port, 2 grab sampling events per test run (at the beginning and end of the test run)	Disinfectant concentration

a: cfu = colony forming units, mpn = most probably number, mg/L = milligrams per liter

The information in Table 2-2 highlights critical parameters for treatment. The initial bacteria concentration was required to evaluate inactivation rates. The presence of ozone, while difficult to measure precisely was identified in treatment grab samples to verify effectiveness of the system. A total of 10 samples were collected per run: 5 initial samples were drawn from the AOP cart at the intake, 1 sample directly from the mixing tank, and 4 treated samples were drawn from the effluent. Ozone sampling was tested prior to treatment and following. Neither sample provided consistent results suitable for reporting. Due to the rapid reactivity of ozone the ability to accurately sample was diminished and at time resulted in complete absence.

Table 2-3. Non-critical Experimental Measurements

Measurement	Reporting Unit[a]	Sample Type	Sampling Location	Sampling Frequency
Total Suspended Solids	mg/L	Each sample per run	Supply tank and outlet sample ports	10 sampling events per test run (T, C0, C5, C10, C15, C20, E5, E10, E15, E20)
Temperature*	ºC	Analog gauge reading	On-line gauge	2 readings per test run (at the beginning and end of the test run)
Flow rate*	gpm	Digital flow meter reading	On-line meter	2 readings per test run (at the beginning and end of the test run)
Water pressure*	psi	Analog gauge reading	On-line gauge	2 readings per test run (at the beginning and end of the test run)
Air flow into the ozone generator*	scfh	Flow meter	On-line meter	2 readings per test run involving ozone (at the beginning and end of the test run)

A: mg/L = milligrams per liter; gpm = gallons per minute; psi = pounds per square inch; scfh = standard cubic feet per hour, * = Process data

The experimental measurements indicated in Table 2-3 are indications of quantifiable characteristics monitored for each test run. Total suspended solids were observed for each sampling event drawn during a treatment run. This provided 10 incidences of TSS observation to evaluate how sediment behaved in the system. Temperatures were controlled by the ambient conditions of the day and did not fluctuate drastically. Flowrate, water pressure, and air flow were determined by inline sensors on the AOP cart. Maintaining consistent measurements provided uniformity by which to compare results.

Table 2-4. Water Quality Measurements

Measurement	Reporting Unit[a]	Sample Type	Sampling Location	Sampling Frequency
*TDS	mg/L	Sample from supply tank	Mixing Tank	1 sampling every test run
*Conductivity	m S/cm	Sample from supply tank	Mixing Tank	1 sampling every test run
*Total N	ppm	Sample from supply tank	Mixing Tank	1 sampling every test run
*Total P	ppm	Sample from supply tank	Mixing Tank	1 sampling every test run
COD	mg/L	Sample from supply tank	Mixing Tank	1 sampling every test run
pH	Standard unit	Sample from supply tank	Mixing Tank	1 sampling every test run
TSS	mg/L	Sample from supply tank	Mixing Tank	10 samplings every test run

mg/L = milligrams per liter; ppm = parts per million; m S/cm = micro Siemens per centimeter

*Conducted by Kansas State Soil Testing Lab

The measurements in Table 2-4 are indicative of the water quality between test batches. Depending on source, settling time, and the discrete sampling these values fluctuated throughout testing. Correlations of these measurements with inactivity were used to compare water quality as it affects AOP treatment.

SAMPLING AND MEASUREMENT APPROACH AND PROCEDURES

Sampling Procedures

The sampling points were located in the supply tank and two outlets of the AOP system as shown in Figure 2-1. Samples for critical parameters (microbial contaminants) as well as non-critical parameters were collected at the frequency presented in Table 2-2 and Table 2-3. Sampling containers, preservation techniques, and holding times for grab sample measurements are presented in Table 3-1. As soon as practical, each sample was aliquoted into the proper containers and the appropriate preservation technique were applied in accordance with the guidelines in Table 3-1. Each container was labeled with the date and time sampled, sample location (inlet or outlet), and the parameters for analysis.

Table 3-1. Sample Containers, Preservation Method, and Holding Times for Grab Sample Parameters

Parameter	Sample Container	Preservation Method	Holding Time
E. coli	Sterile 200 ml glass sample bottle	Cool to 4 ± 2 °C	24 hours from collection
Ozone	200-ml glass bottle	None	Samples analyzed immediately in the field
pH	200-mL glass bottle	Cool to 4 ± 2 °C	Samples analyzed immediately, or held for no more than 4 hours
TSS	200 ml glass sampling bottle	Cool to 4 ± 2 °C	Samples analyzed immediately, or held for no more than 48 hours

Preservation Procedure for Microbial Samples

Microbial samples from the supply tank and AOP unit influent/effluent were collected in 200 ml glass sampling bottles. Once the bottles were full the samples were immediately analyzed or placed in a refrigerator at 4 ± 2 °C until analysis.

Analytical Laboratories

All analyses and measurements listed in tables 2-2 and 2-3 were conducted at Kansas State University with the Kansas State University Soil Testing Lab performing additional analysis to characterize the water samples.

Sampling and Analytical Procedures

Analytical procedures are summarized in Table 3-2. The AOP system is outfitted with inlet and outlet sample taps. When collecting a grab sample, the sample tap was opened and water allowed to flow for approximately 10 seconds to flush the sampling port.

Table 3-2. Analytical Methods for Grab Sample Parameters

Parameter	Units[a]	Method	Citation	Method Summary
E. coli	mpn/ml	9221 B, C	Standard Methods for Examination of Water and Wastewater, 22nd Edition	Colilert reagent and quanti-tray 2000
Ozone	mg/L	4500-O_3-B	Standard Methods for Examination of Water and Wastewater, 22nd Edition	Colorimetric, Indigo dye method
pH	pH units	150.1	EPA/600/4-79-020, Methods for the Chemical Analysis of Water and Waste, March 1983	Litmus paper strips
TSS	mg/L	SM 2540 D	Standard Methods for Examination of Water and Wastewater, 22nd Edition	
*TDS	mg/L	SM 2540C	Standard Methods for Examination of Water and Wastewater, 22nd Edition	
COD	mg/L	SM 5200D/Hach 8000	Standard Methods for Examination of Water and Wastewater, 22nd Edition	
*Conductivity	µS/cm	SM 2510	Standard Methods for Examination of Water and Wastewater, 22nd Edition	
*Total N		USGS WRIR 03-4174	USGS WRIR 03-4174	
*Total P		USGS WRIR 03-4174/EPA 365.2	USGS WRIR 03-4174	

[a]; mg/L = milligrams per liter., mpn=most probable number, cfu=colony forming units
* Conducted at the Kansas State University Soil Testing Lab (http://www.agronomy.k-state.edu/services/soiltesting/)

Samples were labeled in accordance with the following identification scheme: date, sample location, sample time, and experiment number. Temperature, flow and pressure readings were recorded 2 times per test run (at the beginning and the end of the test run). The number of tests completed is delineated in Table 3.3.

Table 3-3. Test Run Summary

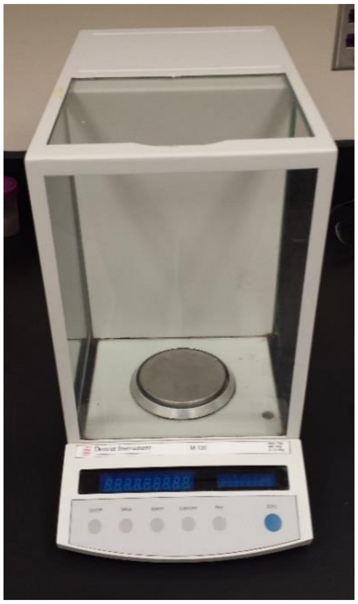
Test Run	Source Water	Flowrate (gpm)	TSS (mg/L)	Source Volume	Run Time
BL	Tap	6	0	100	10
LW1	Lagoon	4	197	100	20
LW2	Lagoon	4	121	100	20
LW3	Lagoon	3.5	70	100	20
PW10	Pond	6	52	150	20
PW11	Pond	6	110	150	20
PW12	Pond	6	70	150	20
PW2	Pond	6	49	100	10
PW3	Pond	5.5	65	150	20
PW5	Pond	6	682	150	20
PW6	Pond	3	155	150	20
PW7	Pond	6	50	150	20
PW8	Pond	3	278	100	20
PW9	Pond	3	176	100	20
TW1	Tap	4	67	100	20
TW3	Tap	4	210	100	20

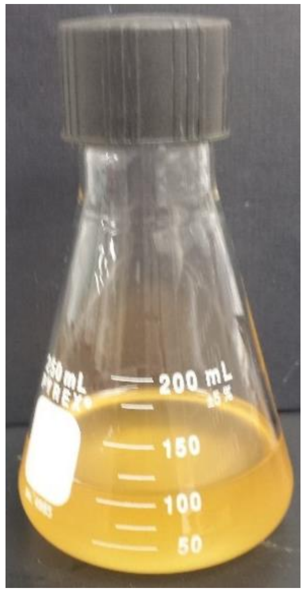
The information in Table 3-3 lists the source for each test batch of water, its characteristic properties, and flowrate maintained during treatment. Tests were labeled according to the sequence of the batch and the associated source of water. The extended runtime of 20 minutes was applied to all, but two tests to provide additional sampling times as the 1 minute sampling time was omitted after verification that tap water chloramines were interfering with AOP inactivation.

Preparing and running the AOP trailer for an individual test required approximately 2 hours per run with 24 hours of preparation between tests for bacteria propagation and final enumeration. Pretreatment maintenance of the AOP trailer entailed flushing of the system for 20 minutes with tap water, loading of source water to supply tank from storage tank at 15-23 minutes, mixing of inoculum bacteria and source water was 20 minutes and 30 minutes for 100 and 150 gallons respectively, and configuration of outlet and inlet hoses to appropriate locations. Setup and decommissioning of equipment for each test run was labor intensive as the area utilized was a common space for multiple projects.

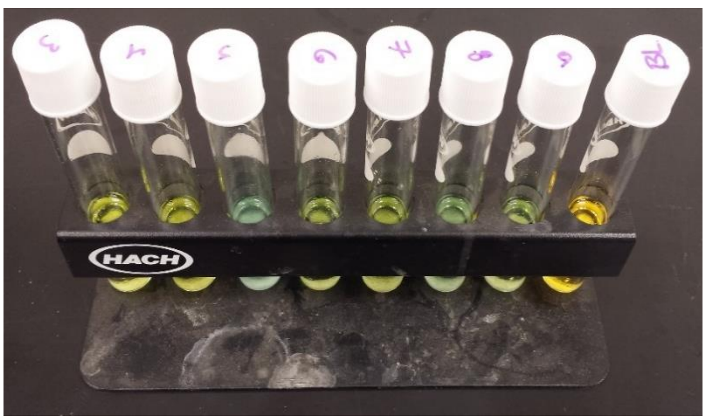
The supply pump from mixing tank to AOP trailer provided a flowrate of ~11 gpm while the small mixing pump circulated water or transferred from the source tank to the mix tank at ~7 gpm.

Bacteria Propagation





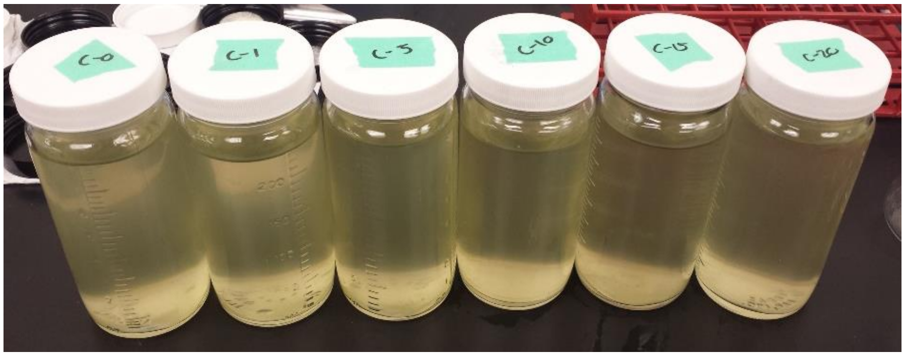
Water Quality Evaluation:
BOD Testing



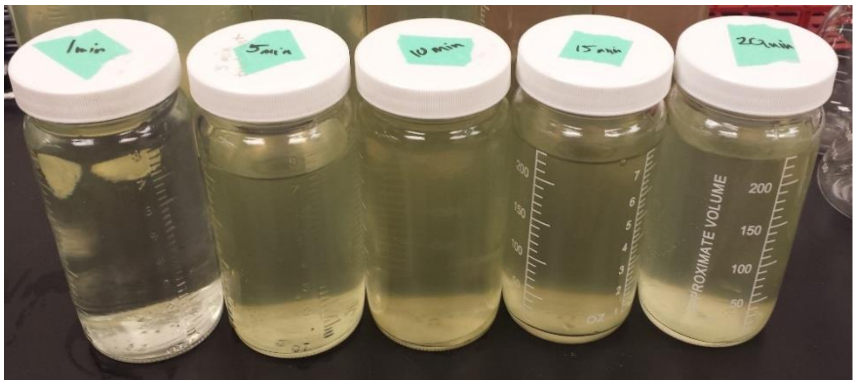
Total Suspended Solids Testing

Sampling glass containers with treated water and high TSS

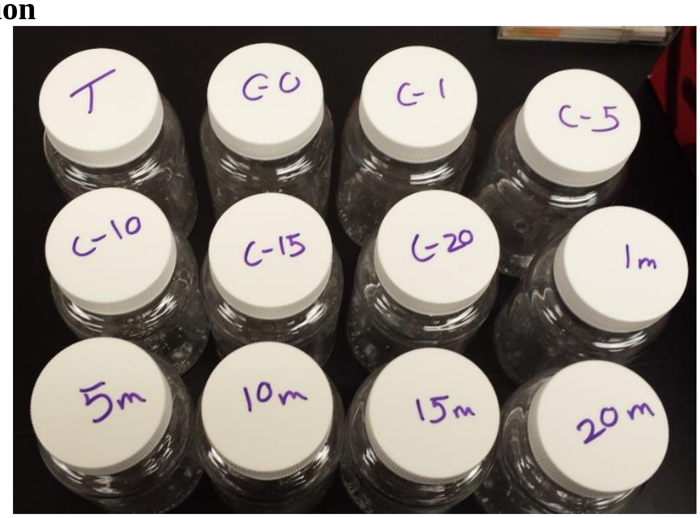
Storage and Labeling



Sampling containers for withdrawing

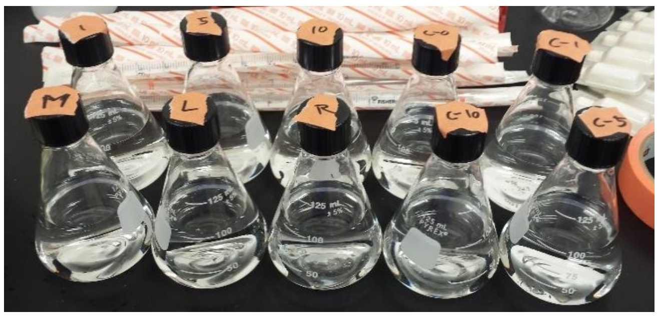


Bacteria Enumeration



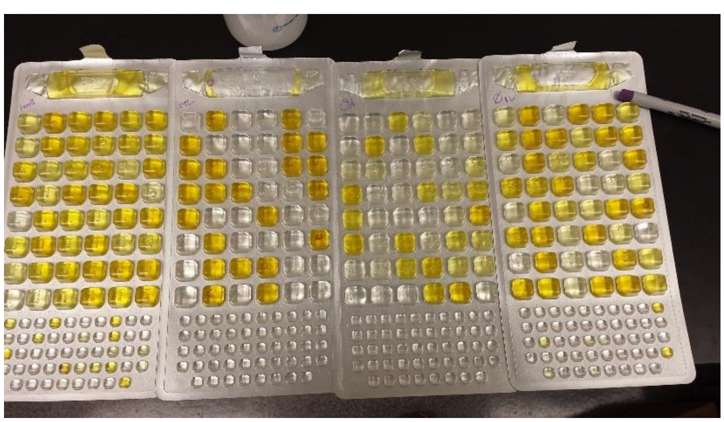
Colilert-18 120 mL vessels with Sodium Thiosulfate labeled for enumeration.

Colilert-18 sodium thiosulfate vessels, reagent snap packets, and Quanti-trays



Treatment sample dilution flasks

Colilert-18 method Quanti-Tray Sealer and



Results and Discussion

The overall results for the AOP treatment do not indicate a connection between inactivation and suspended solids, but there does exist a significant relationship to contact time as indicated by changes in the flow rate. The experimental data showed a correlation to increased inactivation with lower flow rates. Although inactivation was not complete, the once through flow system could be adjusted to recirculate water for additional treatment. Due to time constraints additional testing was not possible, but the benefit could be examined in future research. The relationship of TSS to inactivation was not evident as inactivation occurred in similar distributions whether suspended solids were elevated or reduced.

Resultant Data

Decreased flow rates resulted in a longer period of exposure to the AOP treatment including time for higher levels of ^{-}OH ions to form, and H_2O_2 molecules the opportunity to react prior to O3 destruction. The difference in flow rates from 6 gpm to 4 gpm is not a large gap, but the results demonstrate a significant rate change of inactivation. Increases in flow rate were not tested, but data suggests the recirculation would be necessary for flow rates above 6 gpm.

The information in Table 4-1 expresses the water quality data provided by results from the Kanas State University soil Testing Lab. Tests with incomplete data were not submitted for evaluation, but whose values were determined by standardized lab protocol mentioned in the methods section. Complete water quality evaluations were not conducted for TW1 and TW3.

Table 4-1. Water Quality Measurements

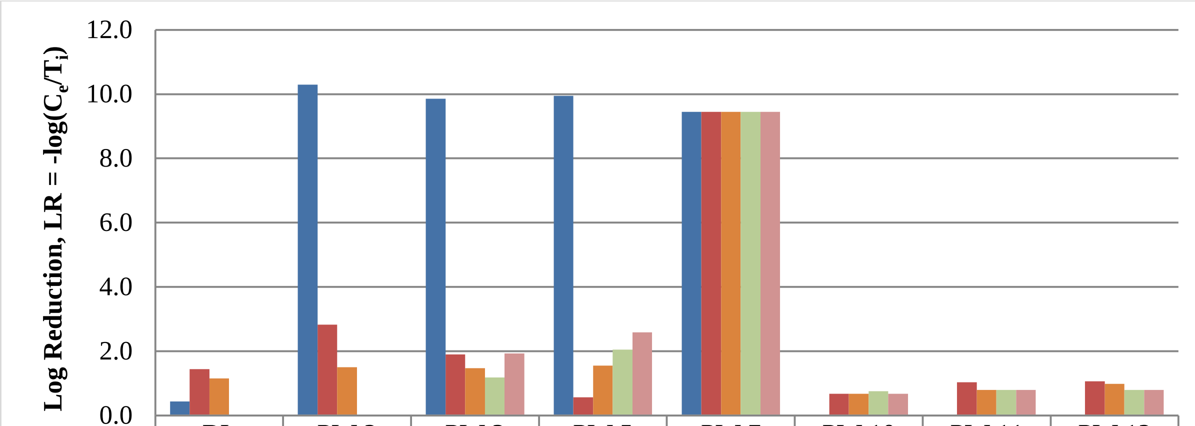
Test	TSS (mg/L)	TDS (mg/L)	Conductivity (m S/cm)	Total N (ppm)	Total P (ppm)	COD (mg/L)	pH
BL	0	0	-	-	-	-	7
PW2	38	-	-	-	-	-	-
PW3	65	648	0.93	11.03	0.9	123	8
PW5	682	569	0.813	15.91	1.66	150	8
PW6	155	616	0.88	13.48	1.22	142	8
PW7	52	571	0.816	15.68	1.17	143	8
PW8	278	591	0.844	17.42	1.36	150	7
PW9	176	601	0.858	15.95	1.23	150	8
LW1	197	356	0.509	4.17	0.33	47	8
LW2	121	368	0.525	4.41	0.34	60	8
LW3	70	365	0.521	3.99	0.29	37	8
PW10	52	573	0.819	10	1.01	145	8
PW11	110	591	0.844	12.71	1.46	150	8
PW12	70	604	0.863	12.18	1.31	155	8
TW1	67	-	-	-	-	-	-
TW3	120	-	-	-	-	-	-
			Statistical Variation				
Average	141	496	0.77	11	1.02	121	8
Minimum	0	0	0.509	3.99	0.29	37	7
Maximum	682	648	0.93	17.42	1.66	155	8
Median	90	573	0.8315	12.445	1.195	144	8
Std Deviation	155	174	0.15	4.66	0.45	43	0.36

Inconsistent inactivation for E1 compared to remaining time intervals was prevalent among all flow rate samplings (Table 4-2). This observation lead to the disregard of E1 sampling times based on the conclusion that chloramine rich tap water was still present in the system at the 1 minute effluent sample time leading to incomparable inactivation. Due to the uncertainty of chloramine level fluctuations prior to the 1 minute sampling times were considered outliers.

Table 4-2. Sequential order of testing and log reductions based on sampling time

Test	**1 min**	**5 min**	**10 min**	**15 min**	**20 min**		**Std Deviation**
BL	0.4	1.4	1.1	-	-		0.4
PW 2	10.3	2.8	1.5	-	-		***3.9***
PW 3	9.9	1.9	1.5	1.2	1.9		***3.3***
PW 5	9.9	0.6	1.6	2.0	2.6		***3.4***
PW 6	9.7	9.7	9.7	9.7	9.7		0.0
PW 7	9.4	9.4	9.4	9.4	9.4		0.0
PW 8	4.8	5.1	5.1	5.3	5.0		0.1
PW 9	6.1	5.8	6.3	5.1	5.0		0.5
LW 1	9.6	5.8	6.3	6.2	6.3		***1.4***
LW 2	4.2	4.2	6.0	5.5	5.2		0.7
LW 3	7.0	5.8	5.6	5.7	5.5		0.5
PW 10	-	0.7	0.7	0.8	0.7		0.0
PW 11	-	1.0	0.8	0.8	0.8		0.1
PW 12	-	1.1	1.0	0.8	0.8		0.1
TW 1	-	2.7	3.8	3.4	2.7		0.5
TW 3	-	3.2	2.8	3.2	2.8		0.2
Average	*7.4*	4.8	4.9	5.6	5.6		

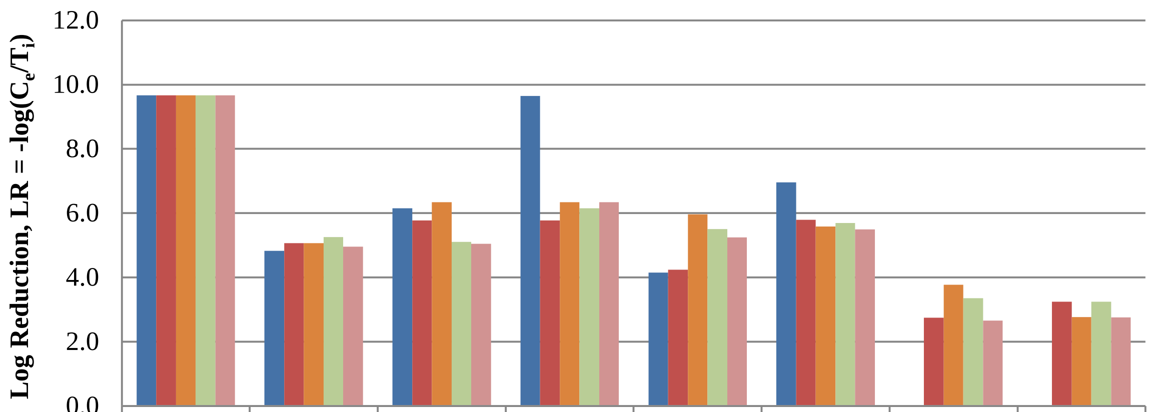
Because inactivation outliers for E1 samples were most common among higher flowrate tests, the data was broken down into two sets for observation. The information in Figure 4-1 demonstrates the performance of the AOP for flow rates exceeding 5 gpm. The reduction observed at 1 minute sampling times expresses the effect of chloramines remaining in the system prior to complete circulation of the batch influent. The system at 1 minute had not yet been purged of tap water used to flush the system before testing.



	BL	PW 2	PW 3	PW 5	PW 7	PW 10	PW 11	PW 12
1 min	0.4	10.3	9.9	9.9	9.4	0.0	0.0	0.0
5 min	1.4	2.8	1.9	0.6	9.4	0.7	1.0	1.1
10 min	1.1	1.5	1.5	1.6	9.4	0.7	0.8	1.0
15 min	0.0	0.0	1.2	2.0	9.4	0.8	0.8	0.8
20 min	0.0	0.0	1.9	2.6	9.4	0.7	0.8	0.8

Figure 4-1. Log Inactivation based on sampling time for High Flowrate

The information presented in Figure 4-2 expresses a similar trend to that of Figure 4-1 with inconsistent reduction for the 1 minute effluent sampling. The trend is not as common for all tests as it is with higher flowrates. The lower rate of reduction could be attributed to the difference between the recirculating pump pressure and the influent pressure. Influent pressure was regulated to determine a high or low flowrate while the circulating pump moved water at a continuous rate. The pump required a minimum pressure of 1 psi in order to continue operation throughout the entire run. Dropping below 3 gpm would in effect lower the pressure to below this threshold.



	PW 6	PW 8	PW 9	LW 1	LW 2	LW 3	TW 1	TW 3
1 min	9.7	4.8	6.1	9.6	4.2	7.0	0.0	0.0
5 min	9.7	5.1	5.8	5.8	4.2	5.8	2.7	3.2
10 min	9.7	5.1	6.3	6.3	6.0	5.6	3.8	2.8
15 min	9.7	5.3	5.1	6.2	5.5	5.7	3.4	3.2
20 min	9.7	5.0	5.0	6.3	5.2	5.5	2.7	2.8

Figure 4-2. Log Inactivation based on sampling time for Low Flowrate

Uniformity of inactivation indicates the chloramines would have to be evenly distributed throughout the system. The lower flow rate may have permitted slower introduction of bacteria to treatment and thus to chloramine presence. While the in-flow rate was lowered the recirculation pump on the cart was not altered. Flowrate to the system was adjusted by increasing or decreasing inlet pressure. The rate at which the circulation pump moves the water would not be changed. Chloramine would have had adequate time to be flushed from the system without mixing of the two streams. The inactivation of 1 minute sampling times were disregarded by this reasoning.

Table 4-3. Influent and Average Effluent rates for individual test

Test	Influent (mpn/mL)	Effluent (mpn/mL)	Percent Reduction (%)	Log Reduction
BL	1.99E+05	1.06E+04	94.67	1.27
PW2	1.99E+05	3.31E+03	98.33	1.78
PW3	7.22E+04	2.24E+03	96.90	1.51
PW5	8.88E+04	6.93E+03	92.20	1.11

PW6	4.62E+04	1.00E+00	100.00	4.66
PW7	2.81E+04	1.00E+00	100.00	4.45
PW8	1.71E+04	1.45E-01	100.00	5.07
PW9	4.37E+04	2.07E-01	100.00	5.33
LW1	4.43E+04	3.65E-02	100.00	6.08
LW2	3.45E+05	5.82E+00	100.00	4.77
LW3	9.10E+04	2.15E-01	100.00	5.63
PW10	1.14E+05	2.31E+04	79.67	0.69
PW11	1.52E+05	2.17E+04	85.69	0.84
PW12	1.50E+05	1.92E+04	87.18	0.89
TW1	3.65E+05	4.21E+02	99.88	2.94
TW3	1.75E+04	2.03E+01	99.88	2.94

Effluent averages omitted the E1 sampling time due to incongruity throughout testing to the remaining sampling times. The pervasiveness of chloramine disinfection from the tap water used to prime the AOP cart contributed inconclusive results. The value for effluent (E_A) was determined from the average of E5, E10, E15, and E20 treated samples. The percent reduction was based on the difference of the initial (T) and effluent average reduction (E_A). Log Reduction values utilized the initial (T) and effluent average reduction (E_A).

Data Analysis

The value of total suspended solids ranged from 0 mg/L to 682 mg/L between 16 treatment samples. Values for TSS were collected from water quality testing by the Kansas State University Soil Testing lab. The rate of reduction indicates the elimination of bacteria based on percentage of inactivation from original values. The standard error for log reduction within each grouping of TSS levels reinforced the evidence that particulates were not a significant hindrance to a UV/O3 AOP. Figure 4-2 illustrates groupings of TSS ranges and the relative inactivation rates. For 0-60 mg/L the reduction averaged 93.17% with similar rates for 60-100 mg/L and 100-160 mg/L at 95.99% and 95.23%. The highest TSS levels or <160 mg/L experienced the highest rate of inactivation with 98.42%. The various groups represent 3-5 tests without distinguishing flowrate. The error bars represent standard deviation within the data groups. Reduction values were based on the average of inactivation for all associated effluent sampling times.

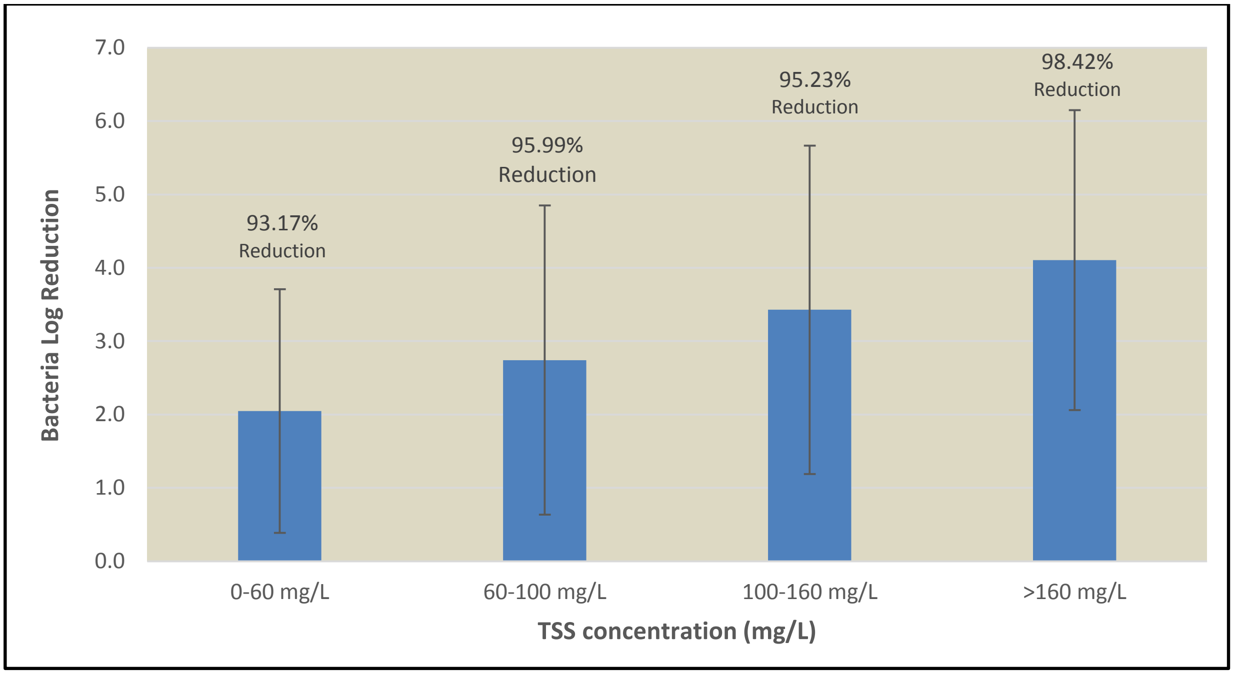


Figure 4-2. Log Inactivation of Bacteria relative to TSS concentration in mg/L.

Experimentation involved direct evaluation of highly turbid water from a runoff collection pond. Test sampling was expanded to 20 minutes with 150 gallons of water and 10 vials of 100 mL E. coli. To establish a baseline for comparison a dechlorinated tap water test was run with the 100 gallons of water and 8 vials of 100 mL E. coli with Tank samples reduced to a singular sample drawn from the middle. Bacteria concentrations and TSS levels were determined as consistent through several split samplings using Left, Right, and Middle collection points. One of the most important notes of the literature review dictates that contact time with ozone disinfection is vital. By reducing the flowrate to just above 3 gpm the level of inactivation was increased by 2-3 logs. Figure 4-3 illustrates the data as separated by difference of flowrate relative to percent inactivation. The two groupings, 6 gpm and 4 gpm, each consist of 8 individual tests and their average reduction. The error bars represent the standard deviation of inactivation within the two groups. Average reduction at a flowrate less than 4 gpm was significantly different than of flowrates of 6 gpm.

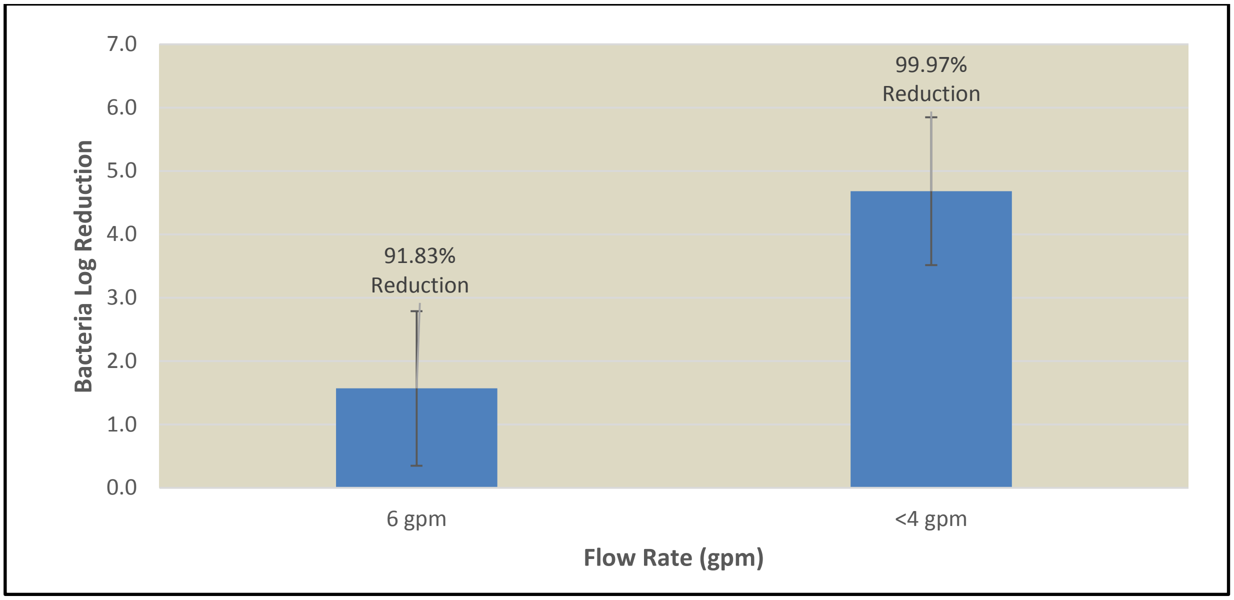


Figure 4-3. Log Inactivation of Bacteria relative to Flow rate in gpm.

Relation of Suspended Solids

The question of whether TSS was influential to the treatment process required closer observation of TSS levels and distribution. Analysis of TSS values, from 100 mg/L to 600 mg/L, resulting in similar reduction. Despite the increase of TSS the reduction ability of the AOP trailer remained uninhibited. In addition, higher TSS correlated with lower flowrates expressing the possibility of settling within the equipment, which would be expected to further hinder inactivation. At higher flowrates the relative TSS levels averaged 135 mg/L while at lower flowrates 160 mg/L.

Statistical Analysis

Is bacteria inactivation dependent on flow rate? The independent variable of flowrate was compared against the response variable, level of inactivation (Table 4-5). The high F value indicates a greater variation between the two scenarios rather than within the samples groups indicating flowrate is a significant contributor to inactivation. Flowrate can be observed as a relation to contact time, or the time of exposure to the treatment process. The connection between contact time and inactivation has been well established in the literature in reference to oxidation reactions and the advanced oxidation reactions occurring in the UV/O3 system. By reducing the flowrate, even marginally by 2 gpm, the rate of inactivation increased substantially. In a system requiring additional contact time the alternative to reducing flowrate would be repeated treatment or recirculation through the treatment system. This holds potential for future research on the matter.

Table 4-5. Single Factor ANOVA: Flow Rate

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Low	8	37.42194	4.677743	1.360293
High	8	12.54557	1.568197	1.484671

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	38.67711	1	38.67711	27.18988	0.000131	4.60011
Within Groups	19.91475	14	1.422482			
Total	58.59186	15				

Variation between groups is lower than variation within groups of high and low TSS (Table 4-6). The low F statistic illustrates this relationship indicating that TSS does not have a significant influence on inactivation. The variation within the data shows that whether or not TSS is elevated does not influence effectiveness of the UV/O3 AOP to inactivate E. coli. The same principle is established in the literature in reference to ozonation, but not for UV irradiation. Because an AOP works in combination of the effects of UV and ozone the deficiency of ultraviolet irradiation as it is interfered with by particulate matter is overcome by the presence of ozonation and oxidation products

Table 4-6. Single Factor ANOVA: Total Suspended Solids

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Low	8	19.15929	2.394912	3.220706
High	8	30.80822	3.851028	3.937974

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.481098	1	8.481098	2.369459	0.146022	4.60011
Within Groups	50.11076	14	3.57934			
Total	58.59186	15				

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Conclusions and Observations

From the results of the AOP treatment, the most imperative parameter can be isolated as the contact time, which is limited by flow rate. The ability of the AOP system to overcome interference of particulates from a variety of water sources demonstrates the potential of the system and its applicability across a broad spectrum.

Many studies have been conducted to reinforce the ability of an AOP to degrade chemicals, particularly organics, but the verification of its multiplicity as it applies to pretreated sources has not been examined as here in.

In addition to the work performed in this study further testing could be used to evaluate the definitive capacity of the system to inactivate bacteria by recirculation, and therefore longer treatment contact. The ability to rule out interference from sediment and particulate matter is a valuable time saving tool. Filtration of water usually precludes treatment to eliminate reactivity consumption by particulates, but within the UV/O3 system this may not be necessary initially. Depending on use of the water source the need to filtrate may be secondary to disinfection.

Information Transfer Program Introduction

The KWRI is committed to transferring knowledge generated by its researchers to clientele. The KWRI uses a variety of methods. These include:

1. The third statewide Kansas "Governor's Conference on the Future of Water in Kansas Conference" was held on November 18-19, 2015 in Manhattan, Kansas. The conference was highly successful with 570 people attending on Day One and 555 attending on Day Two of the conference. Attending the conference was the Governor of Kansas, Sam Brownback, and several state and national senators and representatives. The Governor fully supports this conference and has expressed his concern about the issue of preserving and protecting the future viability of water in Kansas. Thirty-eight volunteer scientific and 5 invited presentations were presented in plenary and concurrent sessions. A showing of the film “When the Wells Run Dry” was presented at the Flint Hills Discovery Center. Ten Faculty/Staff/Professional scientific posters were presented in the poster session. Twenty-one student posters were presented during the poster session. An undergraduate/graduate student poster award program was conducted to encourage student participation. The program agenda is included with this report. The conference will be held again on November 14-15, 2016. The conference website is located at: http://www.kwo.org/Projects/Governors-Conference.html

2. The KWRI website, http://www.kcare.k-state.edu/, is used to transfer project results and inform the public on issues and scientists on grant opportunities.

3. A Kansas Center for Agricultural and the Environment/Kansas Water Resources Institute E-Newsletter was distributed through the Kansas State University website in December, 2015. Topics included Using Tree Revetments for stream stabilization, The Governor’s Water Conference and Irrigation Research in Kansas.

Support for the Governor

Basic Information

Title:	Support for the Governor
Project Number:	2014KS175B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	KS-001
Research Category:	Not Applicable
Focus Category:	Water Supply, Water Quality, Education
Descriptors:	None
Principal Investigators:	Dan Devlin, Susan P Brown

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Governor's Conference on the Future of Water in Kansas

2015

November 18-19, 2015

Hilton Garden Inn & Conference Center
Manhattan, Kansas

Hosted By:

Kansas Water Office

K·STATE Research and Extension

Kansas Water Resource Institute

Kansas Department of Agriculture
Kansas Department of Health & Environment
Kansas Department of Wildlife, Parks & Tourism

AGENDA - Day 1

Wednesday, November 18, 2015

Breakfast Available at 7:30 am

Kaw Nation & Big Basin Rooms

8:15 - **Registration/Tour Exhibits** *(Foyer)*

9:15 - **Opening Session**

- **Presentation of Colors/Welcome**
  Gary Harshberger, Chairman, Kansas Water Authority
- **Governor Sam Brownback - Moving Forward**
  Water Legacy Award Presentation
- **Vision for the Future of Water in Kansas**
  First Year of Implementation **-** *Governor's Vision Team*

12:15 - **Lunch**

1:15 - **"Influencer-The New Science of Leading Change"**
Dr. Stacy Nelson, VitalSmarts-Crucial Conversations-Crucial Accountability-Influencer-Change Anything

2:15 - *Break & Tour Exhibits*

2:40 - **Watershed+ Implementation & Development-Calgary, Canada**
Tristan Surtees & Charles Blanc, Sans façon: WATERSHED+ Project Implementation & Development

3:20 - *Questions & Discussion*

3:35 - **Regionalization of Water Supplies in Minnesota**
Dominic Jones, Red Rock Rural Water System, Minnesota

4:15 - *Questions & Discussion*

4:25 - **Final Wrap Up**
Questions & Discussion & Final Comments

5:00 - **Evening Social at Flint Hills Discovery Center -** *(5:00 pm - 6:30 pm)*

Concurrent Sessions - Day 2

11:00 - **Concurrent Session 4** *(Continued)*
C. Sedimentation *(Alcove)*
Moderator: Ed Martinko, Kansas Biological Survey

- Using Existing Radiological Data Sets to Identify Sediment Sources in John Redmond Reservoir
  Dan Haines
- Restoring Sediment Continuity to the Kansas River Watershed: Benefits & Practicality of Environmental Flows of Sediment
  John Shelley

11:40 - ***Break/View Posters***

11:50 - **Concurrent Session 5**
A. Municipal & Industrial Water *(Flint Hills, Kings & Konza)*
Moderator: Margaret Fast, Kansas Water Office

- Promoting the Value of Water Utilities: Telling the Water Story
  Tonya Bronleewe
- NEPA & 404 Permitting for Two Missouri Water Supply Reservoirs
  Aaron Ball, Chad Johnson

B. Irrigation Efficiency *(Ft. Riley & Big Blue)*
Moderator: Jonathan Aguilar

- Comparing Mobile Drip Irrigation to Low Elevation Spray Application in Corn
  Isaya Kisekka, Gia Nguyen, Jonathan Aguilar, Danny Rogers
- Long Term Water Strategy Planning Using the Crop Water Allocator Program
  Danny Rogers, Jonathan Aguilar, Isaya Kisekka, Freddie Lamm

C. Surface & Groundwater Interaction & Management *(Alcove)*
Moderator: Chris Beightel, KDA-DWR

- Evaluating Future Water Management Strategies in the Lower Republican River Basin
  Christian Gnau, Andrea Brookfield
- Variability of Groundwater/Surface Water Interactions along the Arkansas River
  Andrea Brookfield, Ed Reboulet, Brownie Wilson

12:40 - **Lunch** *(Kaw Nation & Big Basin)*

1:20 - **Emcee - Dr. Dan Devlin, KSU**
Presentation of Graduate/Undergraduate Student Poster Awards

1:40 - **Reflections on Water & Education**
Rex Buchanan, Interim Director, Kansas Geological Survey

2:20 - **Closing Words -** *Tracy Streeter, Kansas Water Office*

2:30 - **Adjournment**

2:30 - *Post Conference Meeting of the Education & Outreach Coordination Team*

Concurrent Sessions - Day 2

Thursday, November 18, 2015

10:00 - Concurrent Session 3 *(Continued)*

C. Communicating Water Issues *(Big Basin)*

Moderator: Sharon Ashworth, Kansas Natural Resource Council

- Protect the Source! A Look at How Public Water Supplies can Ensure Safe Drinking Water for Years to Come
  Travis Sieve

D. Sedimentation & Watershed Health *(Alcove)*

Moderator: Belinda Sturm, Kansas University

- Reducing Sediment & Nutrient Losses from Non-Point Sources in the Middle Neosho Watershed
  Gretchen Sassenrath, Vladimir Alarcon, Stacey Kulesza, Xiaomao Lin
- Hydrodynamic Simulation for the Circulation & Sediment Transport in Kansas Reservoirs with Wind & Flood Conditions
  Z. Charlie Zheng, Haidong Liu, Bryan Young

E. Kansas' Water Future *(Ft. Riley & Big Blue)*

Moderator: Jim Butler, Kansas Geological Survey

- Diminishing Water Resources: A Geologist's Perspective
  James Roberts
- Should We Adjudicate the Water Rights to the Ogallala Aquifer?
  Burke Griggs

10:40 - *Break/View Posters*

10:50 - Water Documentary Film *(Discovery Center, 2nd Floor)*

Moderator: Ernie Minton, Kansas State University

When the Wells Run Dry *is a 31 minute film directed by Lawrence filmmaker Steve Lerner, & award winning LA documentary filmmaker Reuben Aaronson. Other members of the production team are Jim Jewell & Greg Allen. This documentary portrays the vital connection that rural Kansans have with water, our most precious resource. Ranchers, farmers & residents of small KS towns tell us their heartfelt, personal stories about water, including the ongoing threats they face to the availability of the water on which they depend. Matthew Sanderson will offer commentary & respond to audience questions & comments.*

11:00 - Concurrent Session 4

A. Water Quality *(Flint Hills, Kings & Konza)*

Moderator: Jaime Gaggero, Kansas Dept. of Health & Environment

- Algal Toxin Removal at Ambient & High pH Conditions
  Jeff Neemann
- Treating Agricultural Runoff with Constructed Wetlands
  Edward Peltier, C. Bryan Young, LlynnAnn Luellen, Hyunjung Lee

B. Irrigation Efficiency *(Ft. Riley & Big Blue)*

Moderator: Joe Harner, Kansas State University

- The Importance of Irrigation Scheduling in the 21st Century
  Freddie Lamm
- Agricultural Crop Water Use
  Danny Rogers, Jonathan Aguilar, Isaya Kisekka, Philip Barnes

AGENDA - Day 2

Thursday, November 19, 2015

Breakfast Available at 7:30 am

7:30 - Registration/View Posters

8:00 - Concurrent Session 1

A. High Plains Aquifer *(Flint Hills, Kings & Konza)*
B. Emerging Issues *(Kaw Nation)*
C. Municipal & Industrial Water *(Big Basin)*
D. Watershed Health *(Alcove)*

8:40 - *Break/View Posters*

9:00 - Concurrent Session 2

A. Water Data & Projections *(Flint Hills, Kings & Konza)*
B. Emerging Issues *(Kaw Nation)*
C. Municipal & Industrial Water *(Big Basin)*
D. Sedimentation & Watershed Health *(Alcove)*

9:40 - *Break/View Posters*

10:00 - Concurrent Session 3

A. Water Quality *(Flint Hills, Kings & Konza)*
B. Water Planning & Implementation *(Kaw Nation)*
C. Communicating Water Issues *(Big Basin)*
D. Sedimentation & Watershed Health *(Alcove)*
E. Kansas' Water Future *(Ft. Riley & Big Blue)*

10:40 - *Break/View Posters*

10:50 - Water Documentary Film - *(Discovery Center, 2nd Floor)*

11:00 - Concurrent Session 4

A. Water Quality *(Flint Hills, Kings & Konza)*
B. Irrigation Efficiency *(Ft. Riley Room & Big Blue)*
C. Sedimentation *(Alcove)*

11:40 - *Break/View Posters*

11:50 - Concurrent Session 5

A. Municipal & Industrial Water *(Flint Hills, Kings & Konza)*
B. Irrigation Efficiency *(Ft. Riley Room & Big Blue)*
C. Surface & Groundwater Interaction & Management (*Alcove)*

12:40 - Lunch

1:20 - Student Poster Awards- Dan Devlin, KSU

1:40 - Reflections on Water & Education

Rex Buchanan, Interim Director, Kansas Geological Survey

2:20 - Closing Words - *Tracy Streeter, Director, Kansas Water Office*

2:30 - *Adjourn*

2:30 - *Post Conference Meeting of the Education & Outreach Coordination Team*

Concurrent Sessions - Day 2

Thursday, November 19, 2015

8:00 - Concurrent Session 1

A. High Plains Aquifer: Conserve & Extend *(Flint Hills, Kings & Konza)*

Moderator: Lane Letourneau, Kansas Dept. of Agriculture

- Assessing Prospects for Sustainability in the High Plains Aquifer in Kansas
  James Butler, Donald Whittemore, Brownie Wilson
- Monitoring Impacts of the Sheridan County 6 Local Enhanced Management Area (LEMA)
  Bill Golden

B. Emerging Issues *(Kaw Nation)*

Moderator: Joe Pajor, City of Wichita

- Long Term Water Supply: What Will the Climate Look Like - The National Climate Assessment
  Doug Kluck
- Drought Tournaments - This is Not a Game, Well It Is.
  Margaret Fast

C. Municipal & Industrial Water *(Big Basin)*

Moderator: Mike Tate, Kansas Dept. of Health & Environment

- Risk to City's Water Supply Mitigated with Quick Actions
  Andrea Cole
- Long-Term Water Supply Planning - Two Cities, Two Battles, One Future
  Brian Meier, Luca DeAngelis

D. Watershed Health *(Alcove)*

Moderator: Stacy Hutchinson, Kansas State University

- Unifying Watershed Management Through an Off-Site BMP Implementation Program in the Little Arkansas River Watershed
  Trisha Moore, Ron Graber, Josh Roe, Tom Stiles
- Understanding the Relationship between Urban Best Management Practices & Ecosystem Service Provision
  Kelsey McDonough, Trisha Moore, Stacy Hutchinson

8:40 - *Break/View Posters*

9:00 - Concurrent Session 2

A. Water Data & Projections *(Flint Hills, Kings & Konza)*

Moderator: Andy Ziegler, USGS

- Using Radar Precipitation to Estimate Water-Level Changes & Water Use in the High Plains Aquifer
  Don Whittemore, James Butler, Brownie Wilson, John Woods
- USGS Water Data Available on the Internet
  Brian Loving

9:00 - Concurrent Session 2 *(continued)*

B. Emerging Issues *(Kaw Nation)*

Moderator: Earl Lewis, Kansas Water Office

- Water Transfers & Applicability for Kansas
  Les Lampe, Klint Reedy, Lela Perkins
- Legal & Legislative Evaluation of Kansas Aqueduct Study
  David Pope

C. Municipal & Industrial Water *(Big Basin)*

Moderator: Andrew Swindle, Wichita State University

- Developing a Systematic Approach to Implement a Groundwater Reverse Osmosis Facility
  Jake White
- Osage City Lake Restoration Project
  Randy Root

D. Sedimentation & Watershed Health *(Alcove)*

Moderator: Bobbi Luttjohann, Kansas Water Office

- Streambank Restoration - A Unified Effort to Increase Agency Coordination & Efficient Delivery of Resources
  Rob Reschke, Jaime Gaggero, Steve Frost
- Implementing WRAPS Plans . . . The Details
  Andrew Lyon, Graham Freeman

9:40 - *Break/View Posters*

10:00 - Concurrent Session 3

A. Water Quality *(Flint Hills, Kings & Konza)*

Moderator: Erika Stanley, Kansas Water Office

- Non-Point Source in the News: How it Relates to Kansas
  Jaime Gaggero
- Fate of High Uranium in Saline Arkansas River Water in Southwest Kansas: Distribution in Soils, Crops & Groundwater
  Don Whittemore, Masato Ueshima, Jonathan Aguilar, G.L. Macpherson

B. Water Planning & Implementation *(Kaw Nation)*

Moderator: Susan Stover, Kansas Geological Survey

- Implementing the Water Vision: Changes to Rules & Regulations
  Susan Metzger, Lane Letourneau, David Barfield
- Nebraska's New Water Sustainability Fund: Its Origin, Status & Applicability in Kansas
  Karen Griffin, Patti Banks

C. Communicating Water Issues *(Big Basin)*

Moderator: Sharon Ashworth, Kansas Natural Resource Council

- Communicating about Conservation Practice Needs Using Spatially Enabled PDF Maps
  Will Boyer

Governor's Conference on the Future of Water in Kansas
Poster Presenters

Faculty/Staff/Professional

1. **Kansas High Priority Watersheds that Intersect with Threatened or Endangered Species Habitats**
   Susan Brown, Kansas Center for Agricultural Resources and the Environment, Kansas State University Research and Extension
   Robert Wilson, Office of Local Government, Kansas State University Research and Extension

2. **Hydrological Transitions: The Story of Kansas Watersheds**
   Christy Jean, Geography, Kansas State University

3. **Cedar Tree Revetment Demonstration – Partners Working to Protect Streams**
   Bob Culbertson, Watershed Restoration and Protection Program, Kansas Alliance for Wetlands and Streams
   Wes Fleming, Watershed Restoration Protection Program, Kansas Alliance for Wetlands and Streams

4. **Effect of May through July 2015 Storm Events on Suspended Sediment Loads, Sediment Trapping Efficiency, and Storage Capacity of John Redmond Reservoir**
   Guy Foster, Kansas Water Science Center, U.S. Geological Survey

5. **Sediment Oxygen Demand in Eastern Kansas Streams**
   Lindsey King, Studies Section, U.S. Geological Survey
   Guy Foster, Studies Section, U.S. Geological Survey
   Jennifer Graham, Studies Section, U.S. Geological Survey

6. **Water Use in Kansas**
   Jennifer Lanning-Rush, Kansas Water Science Center, U.S. Geological Survey
   Andy Terhune, Division of Water Resources, Kansas Department of Agriculture
   Ginger Pugh, Division of Water Resources, Kansas Department of Agriculture

7. **Increasing Landowner Interest for Streamside Vegetation in the Tuttle Creek Reservoir Watershed of Kansas**
   Thad Rhodes, Kansas Forest Service, Kansas State University

8. **Groundwater-Level and Storage-Volume Changes in the Equus Beds Aquifer near Wichita, Kansas, Predevelopment through January 2015**
   Mandy Stone, Department of the Interior, U.S. Geological Survey
   Joshua Whisnant, Department of the Interior, U.S. Geological Survey
   Cristi Hansen, Department of the Interior, U.S. Geological Survey
   Patrick Eslick. Department of the Interior, U.S. Geological Survey

9. **Nutrient Fate and Transport in Indian Creek, Johnson County, Kansas**
   Thomas Williams, Studies Section, U.S. Geological Survey
   Jennifer Graham, Studies Section, U.S. Geological Survey
   Guy Foster, Studies Section, U.S. Geological Survey

10. **"If It Were Me…" Explaining Aquifers with Interactive Exhibits**
    Laurel Zhang, Special Projects, Exploration Place, Inc.

Student Posters

1. **Way$ to Water Wi$dom**
   Morgan Lawrence, Department of Leadership Studies, Water Wi$e Tigers
   Nancy Handley, Fort Hays State University
   Kimber Lang, Fort Hays State University
   Colby Skelton, Fort Hays State University
   Adam Kober, Fort Hays State University
   Christie Brungardt, Fort Hays State University
   Stacie Minson, Watershed Specialist, Kansas State University

2. **Toxic Microplastics Pollution: How Much is Ingested by Aquatic Invertebrates?**
   Sydney Bolin, Department of Ecology and Evolutionary Biology, University of Kansas
   Rachel E. Bowes, Kansas Biological Survey, University of Kansas
   James H. Thorp, Kansas Biological Survey, University of Kansas

3. **Not All Depths are Created Equal: Deep Water Algae Layers Influence Benthic Invertebrate Distribution in Stratified Lakes**
   Emily Arsenault, Ecology and Evolutionary Biology, Kansas Biological Survey, University of Kansas
   Rachel Bowes, Kansas Biological Survey, University of Kansas
   Brendan Martin, Kansas Biological Survey, University of Kansas
   Frank deNoyelles Jr., Kansas Biological Survey, University of Kansas
   James Thorp, Kansas Biological Survey, University of Kansas

4. **Hydrodynamic Simulation for the Circulation and Sediment Transport in Kansas Reservoirs with Wind and Flood Conditions**
   Haidong Liu, Department of Aerospace Engineering, University of Kansas
   Zhongquan Charlie Zheng, University of Kansas
   Bryan Young, University of Kansas

5. **Wheat Yield Responses to Multiple Drought Indices from 1970 to 2007 in Kansas**
   Zachary Zambreski, Department of Agronomy, Kansas State University
   Xiaomao Lin, Department of Agronomy, Kansas State University
   Gerard Kluitenberg, Department of Agronomy, Kansas State University

6. **Downstream Effects: How Water Conservation Policy Flows from State to Municipal Governments**
   Martin Koch, Department of Geography, University of Kansas

7. **The Impact of Climate Change on the Efficiency of Best Management Practices: Case Study of Ephemeral Gully Erosion**
   Vladimir Karimov, Biological and Agricultural Engineering, Kansas State University
   Aleksey Sheshukov, Biological and Agricultural Engineering, Kansas State University

8. **Our Essential Freshwater Source: Estimating the Occurrence and Function of Playa Wetlands in Western Kansas**
   Willow Malone, Department of Biology, Kansas State University
   David A. Haukos, Department of Biology, Kansas State University
   Melinda D. Daniels, Stroud Water Research Center

9. **The Republican River Basin: A Preliminary Analysis of Past, Present, and Future Climate Trends**
   Jean Eichhorst, Geography and Atmospheric Science, University of Kansas

10. **An Analysis of Anthropogenic Phosphorus in Surface and Groundwater at Emporia State University**
    Xinwei Li, Chemistry and Earth Science, Emporia State University
    Katy Schwinghamer, Emporia State University
    Andrew Miller, Emporia State University
    Marcia Schulmeister, Emporia State University

11. **Fish Biodiversity as a Component of Ecosystem Function and Indicator of Environmental Degradation in a Great Plains River**
    Richard Lehrter, Fish and Wildlife Cooperative Unit, Kansas State University

12. **Irrigation Technology Upgrade and Water Savings: Adapting to Weather Variability and Output Price Uncertainty**
    Rulianda Wibowo, Department of Agricultural Economics, Kansas State University
    Sreedhar Upendram, Missouri Department of Natural Resources
    Jeffrey M. Peterson, Water Resources Center, Department of Applied Economics, University of Minnesota

13. **Comparing Soil Water Evaporation and Leaf Area Index under Mobile Drip Irrigation and Low Elevation Spray Application**
    Gia Nguyen, Biological and Agricultural Engineering, Kansas State University
    Isaya Kisekka, Southwest Research and Extension Center, Kansas State University

14. **Springs and Streams of the High Plains Aquifer in Kansas: Examining Impacts of Groundwater Pumpage using Historical Data, Simulated Results, and Interactive Visualization**
    Misty Porter, Department of Geology, University of Kansas
    Mary C. Hill, Department of Geology, University of Kansas

15. **Drivers of Small Dam Construction across Western and Central Kansas – An Analysis of Cropping Intensity and Associated Land-Use Characteristics**
    Sarmistha Chatterjee, Department of Geography, University of Delaware
    Jason Bergtold, Department of Agricultural Economics, Kansas State University
    Marcellus M. Caldas, Department of Geography, Kansas State University
    Melinda D. Daniels, Stroud Water Research Center

16. **Hydrogeologic Characterization of Riverbeds in Western Kansas**
    Weston Koehn, Civil Engineering, Kansas State University
    Sarah D. Auvenshine, Civil Engineering, Kansas State University
    Scott J. Kempin, Civil Engineering, Kansas State University
    Stacey E. Tucker-Kulesza, Civil Engineering, Kansas State University
    David R. Steward, Civil Engineering, Kansas State University

17. **Playa Wetland Morphological Analyses in Western Kansas**
    Melissa Goldade, Department of Geography and Atmospheric Science, University of Kansas
    Jude Kastens, Kansas Biological Survey, University of Kansas
    William C. Johnson, Department of Geography and Atmospheric Science, University of Kansas

18. **Teaching Freshmen about Water, Energy, Food, the Environment, and Public Policy in an Interactive Classroom**
    Adam Yoerg, Department of Biology, University of Kansas
    Sergio Abarca, Tynan Bollinger, Savanna Cox, Derek Engel, Zachary Jeffries, Esteban Miranda, Nikki Pelkey, Matthew L. Shaffer, John Taylor, Christopher VanSomeren
    Advisors: Mary C. Hill, Adam Yoerg, University of Kansas

19. **Evaluating Sediment Contribution and Mapping Areas Sensitive to Ephemeral Gully Erosion in Central Kansas**
    Lawrence Sekaluvu, Biological and Agricultural Engineering, Kansas State University
    Aleksey Y. Sheshukov, Biological and Agricultural Engineering, Kansas State University
    Stacy L. Hutchinson, Biological and Agricultural Engineering, Kansas State University

20. **Basic Information on Groundwater in Kansas**
    Morgan Riggs, Department of Social Sciences, Emporia State University

21. **Estimating River Surface Velocity Using Optical Remote Sensing Techniques**
    Sarah Child, Department of Geology, University of Kansas
    Leigh A. Stearns, Department of Geology, University of Kansas

Special thanks to the Governor's Award judges:
Scott Campbell, Kansas Biological Survey, University of Kansas; Daniel Clements, Burns & McDonnell; Leena Divakar, Kansas Department of Health and Environment; Amber Campbell Hibbs, Kansas State University; Diane Knowles, Kansas Water Office; Andrew Miller, Emporia State University; Ginger Pugh, Kansas Department of Agriculture–Division of Water Resources; Vahid Rahmani, Kansas Biological Survey, University of Kansas; Stan Roth, Kansas Biological Survey, University of Kansas; Susan Stover, Kansas Geological Survey

Kansas Center for Agriculture Resources and the Environment (KCARE) and Kansas Water Resources Institute (KWRI)

Addressing environmental issues in Kansas

DECEMBER 2015

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Governor's Conference on the Future of Water in Kansas

The forth statewide "Governor's Conference on the Future of Water in Kansas Conference" was held on November 18-19, 2014 in Manhattan, Kansas. The conference was highly successful with 570 attendees on Day 1 and 555 attendees on Day 2. Attending the conference and giving the welcome was the Governor of Kansas, Sam Brownback. Several state and national senators and representatives were present. Invited speakers addressed topics such as Influencing Change Conversations, Watershed Implementation and Art, and Regionalization of Water Supplies in Minnesota. Thirty-eight volunteer scientific and 5 invited presentations were presented in plenary and concurrent sessions. A showing of the film "When the Wells Run Dry" was presented at the Flint Hills Discovery Center. Thirty-one scientific posters were presented in the poster session. An undergraduate/graduate student poster award program was conducted to encourage student participation with twenty-one students competing. The next conference will be scheduled for fall of 2016 and anyone is involved in water issues or has an interest in water issues in the state is highly encouraged to attend. Please watch the KCARE website for information.

Leave a reply

Tree revetments

A new innovative approach to stabilizing streambanks is being put into practice in the Upper Lower Smoky River Watershed. Tree revetments are being used for stream bank restoration. These revetments are structures that are created from interlocking trees in the stream in order to slow down the flow of the water and reduce stress on the streambank. They are located along the outside bend of the meandering stream and are intended to mimic a natural system.

In order to make the revetment, a tree that is to be used is harvested and a vertical cut is made into the streambank. The tree is laid in the cut with the root ball in the bank of the stream and the top limbs extending into the middle of the stream at a distance that is no further than 1/3 of the stream bankfull width. The desired length of the tree including the root wad is 30 feet. The branches should be kept intact as much as possible. After the tree is anchored in the bank, the water flow will naturally be directed away from the eroding bank. The calmer water around the tree will create a habitat for aquatic species.

Continue reading →

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KSRE Irrigation Research

Scientists at K-State Research and Extension are studying limited irrigation, subsurface drip irrigation, irrigation scheduling, mobile drip irrigation, water sensors, remote sensing and the economics of irrigation and policy. Irrigation research is aimed at maximizing the use of water to meet the demand for food and forage and to sustain the rural and state economies.

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USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	2	0	0	0	2
Masters	8	0	0	0	8
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	11	0	0	0	11

Notable Awards and Achievements